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3.—A New and Distinctive Species of Eriachne R. Br. (Gramineae) from Western Australia

By M. Lazarides*

Manuscript received—24th February, 1959

A new species of *Eriachne* R. Br. from the Kimberley district of Western Australia is described and illustrated. The prolific branching of the culms from the upper nodes is a unique characteristic within the genus. Its closest affinities are with *Eriachne filiformis* Hartley.

Eriachne fastigiata M. Lazarides sp. nov.

Holotype.—Near Clifton Creek, 2.5 miles N.W. of Glenroy Meatworks, *M. Lazarides* 5142, 22.iv.1955, Fig. 1.

Gramen perenne breviter vivens vel annuum, laxe caespitosum, radicibus fibrosis et innovationibus intravaginalibus. *Culmi* nonnulli, erecti vel obliqui, 27-38 cm alti, ramosi, 2-4-nodosi, striati, glabri vel pilis basi tuberculatis, brevibus, rigidis, laeves vel scaberuli tuberculis paucis dispersis, nodis superioribus geniculati et prominenter fastigiati, inferiores filares et teretes, superiores gracillimi et admodum compressi; internodia inaequalia, basale distincte elongatum, superiora gradatim multo breviora, internodium floriferum elongatum; nodi glabri. *Folia* plerumque basalia, brevia, hispida; *foliorum vaginae* internodiis breviores, dense hispidae pilis basi tuberculatis, patentibus, prominenter striatae, uno margine hyalinae et glabrae, basales arcte imbricatae, superiores admodum laxae; ligula ciliata pilis circa 1 mm longis; collum glabrum. *Laminae* lanceolatae, acuminatae, 1.5-2.5 cm longae, 1.5-3 mm latae, planae (rare admodum incurvae), striis scaberulae, rigide erectae vel admodum recurvae, subtus et marginibus incrassatis dense hispidae pilis longis, patentibus, basi tuberculatis, supra puberulae; prophylla nodis superioribus nonnulla, membranacea, lanceolata, acuminata, marginibus late hyalinis, carinis 2 et nervis nonnullis, carinis plerumque scaberula. *Panicula* 3-4.5 cm longa, 2 mm lata, prominenter exserta, spiciformis, gracilis, erecta, linearis; rhachis filiformis, plana vel angularis, glabra, laevis vel admodum scaberula; rami pauci, filiformes, glabri, laeves, adpressi ad rhachem, usque ad 7 mm longi, breviores paniculae apicem versus, omnes 2-3 (plerumque 2) spiculis; pedicelli graciles, firme erecti, glabri, laeves, admodum incrassati apicem versus, longitudine inaequales, terminales 3.5-4.5 mm longi, laterales 1-1.5 mm longi, apicem paniculae versus breviores ($<$ 1 mm longi). *Spiculae* 3-4 mm longae, apice 1-2 mm latae, lateraliter compressae, adpressae ad et continuae (nonnunquam admodum contiguae) secundum rhachem, plerumque hiantes et tunc cuneatae, nonnunquam ellipticae et admodum acuminatae, maturitate pallido-flavae. *Anthoecia* 2, bisexualia, plano-convexa. *Glumae* persistentes, longitudine sub-aequales, spicula paulum breviores, membranaceae ad scariosae, glabrae, laeves, ellipticae, obtusae, arcte 5-7-nervis, marginibus late hyalinis. *Rhachilla* supra glumas et inter anthoecia disarticulans. *Lemmata* spiculam aequantia, elliptico-ovata (explanata), acuminata, scariosa, 7-nerva, dimidio inferiori dense pubescentia pilis appressis, albis, apicem versus glabra et scaberula. *Paleae* lemmatibus longitudine et textura similes, obtuse 2-carinatae, enervi, apice minute bifidae vel integrae, $\pm$ planae et dense pubescentes inter carinas pilis appressis albis brevibus (nonnunquam apicem versus admodum glabrae); carinae similiter pubescentes, alis late hyalinis glabris laevibus, paulum incurvatis et caryopsidem amplectantibus. *Stamina* 3; antherae 2 mm longae, anguste oblongae. *Ovarium* glabrum; stigma plumosum, purpureum. *Caryopsis* 2-2.5 mm longa, oblongo-elliptica, plano-convexa, obtusa vel mucronata, ventri canaliculati, brunneo-fusca.

Annual or short-lived perennial forming small, loose tufts with fibrous roots and intravaginal innovations. *Culms* several, erect or oblique, 27-38 cm high, branched, 2-4 noded, striate, smooth or sparsely tubercled, glabrous or with few scattered tubercle-based short stiff hairs, geniculate and prominently fastigiate at the upper nodes; the lower internodes wiry and terete, the upper very slender and somewhat compressed; internodes unequal, the basal one distinctly elongated, becoming much shorter upwards except the elongated uppermost; nodes glabrous. *Leaves* mostly basal, short, hispid; *sheaths* shorter than their internodes, prominently striate, densely hispid with spreading tubercle-based hairs, hyaline and glabrous on

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one margin, the basal sheaths imbricate and tight, the upper rather loose; ligule ciliate with hairs about 1 mm long; collar glabrous; *blades* 1.5-2.5 cm long, 1.5-3 mm wide, lanceolate, acuminate, striate, flat (rarely somewhat incurved), scaberulous on the striations, rigidly erect or somewhat recurved, densely hispid with long spreading tubercle-based hairs on the under surface and thickened margins, puberulous on the upper surface; prophylla several from the upper nodes, membranous, lanceolate, acuminate, with broadly hyaline margins, 2-keeled and several-nerved, usually scaberulous on the keels. *Panicle* 3-4.5 cm long, 2 mm wide, spike-like, slender, erect, linear, prominently exserted; rhachis filiform, flat or angular, glabrous, smooth or somewhat scaberulous; branches few, filiform, glabrous, smooth, adpressed to the rhachis, up to 7 mm long, shorter towards the apex of the panicle, each with 2-3 (usually 2) spikelets; pedicels slender, glabrous, smooth, somewhat thickened towards the apex, unequal in length, the terminals 3.5-4.5 mm long, the laterals 1-1.5 mm long, shorter (less than 1 mm long) towards the apex of the panicle. *Spikelets* 3-4 mm long, 1-2 mm wide (at the apex), laterally compressed, adpressed to and continuous (sometimes somewhat contiguous) along the rhachis, usually gaping and then cuneate, sometimes elliptic and somewhat acuminate, pallid-yellow at maturity. *Florets* 2, bisexual, plano-convex. *Glumes* persistent, sub-equal in length, slightly shorter than the spikelet, membranous to scarious, elliptic, obtuse, glabrous, smooth, closely 5-7-nerved, with broadly hyaline margins. Rhachilla disarticulating above the glumes and between the florets. *Lemmas* as long as the spikelet, scarious, elliptic-ovate (flattened), acuminate, unawned, 7-nerved, not sulcate, densely pubescent with appressed white hairs below the middle, glabrous and scaberulous towards the apex. *Paleas* similar to the lemmas in length and texture, obtusely 2-keeled, nerveless, minutely bifid or entire, ± flat and densely pubescent with short white appressed hairs between the keels (sometimes somewhat glabrous towards the apex), the keels similarly pubescent, with broadly hyaline glabrous smooth wings, the wings slightly incurved and embracing the grain. *Stamens* 3; anthers 2 mm long, narrowly oblong. *Ovary* glabrous; stigma plumose, purple. *Caryopsis* 2-2.25 mm long, oblong-elliptic, plano-convex, obtuse or mucronate, channelled on the ventral surface, dark-brown.

Western Australia: Northern Province.—Near Clifton Creek, 2.5 miles N.W. of Glenroy Meatworks, *M. Lazarides* 5142 (HOLOTYPE) Fig. 1 and 5142A, 22.iv. 1955 (PARATYPE) Plate 1. The holotype and two sheets of the paratype are in the C.S.I.R.O. herbarium, Canberra, A.C.T. Fragments of the paratype will be distributed to the State Herbarium of Western Australia, Perth for permanent retention.

This species is unique within the genus by virtue of its densely branching habit from the upper nodes (to which its name refers), its consistently elongated basal internode, and to a lesser extent, its spiciform, linear, very slender panicle. The structure of its panicle, however, approaches that of *Eriachne filiformis* Hartley.

As compared with the paratype, the holotype is a shorter (about 30 cm high), older plant on which biennial inflorescences are predominant. The paratype, on the other hand, is about 38 cm high, possesses fewer innovations and still retains the remnants of its annual panicles.

The species was observed at its type locality and also 10 miles N.W. of Glenroy Meatworks as a common associate of *Melaleuca minutifolia* F. Muell., *Plectrachne pungens* (R. Br.) C. E. Hubbard, and *Sorghum australiense* Garber & Snyder growing in skeletal, stony, shaley areas.

The species is grazed to some extent. It was locally recognised as "windy grass".

PLATE 1

Eriachne fastigiata sp. nov., one sheet of paratype. (Photograph: C. L. Leslie.)

Fig. 1.—*Eriachne fastigiata* sp. nov., from holotype.

A, plant x $\frac{1}{2}$. B, portion of culm and leaf x 10. C, panicle x 10. D, spikelet x 10. E, floret x 10. F, glume x 10. G, lemma x 10. H, palea x 10. I, J, caryopsis x 10.

4.—Tertiary Sediments at Coolgardie, Western Australia

By B. E. Balme* and D. M. Churchill†

Manuscript received—24th February, 1959

Palynological studies have been carried out on carbonaceous sediments from Rollo's Bore and Shaft and Olsen's Claim, all located about 1½ miles east of Coolgardie Railway Station. The results of these examinations indicate the presence of about 400 feet of Upper Eocene or Lower Oligocene strata, lying in a small depression in the Precambrian Shield. The section in Rollo's Bore includes brown coal, carbonaceous clays and immature boghead coal. These sediments are considered to be of lacustrine origin and to have been deposited, possibly in a coastal lake, during a physiographical cycle initiated by the epeirogenic movements accompanying the Upper Eocene marine transgression.

Pollen grains of *Nothofagus* are abundant in the sediments and are associated with pollens of proteaceous and podocarpaceous affinities. These microfloral assemblages represent the farthest inland and most northerly occurrence of the Lower Tertiary "*Nothofagus*-flora" yet recorded from Western Australia.

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Introduction

Precambrian igneous and metamorphic rocks in the Coolgardie area are usually obscured by deposits of alluvial, eluvial or chemical origin. Blatchford (1899) described these superficial deposits in some detail, and recently McMath (in McMath, Gray and Ward, 1953) proposed a classification of them. He recognized residual or eluvial soils, alluvial and aeolian deposits, laterites, and "cements" formed *in situ* by the decomposition of basement rocks. In most places in the Coolgardie district these deposits are undoubtedly a product of the present physiographic cycle and seldom exceed five or six feet in thickness.

Sediments of an entirely different type, however, are known in a small area lying to the east and south-east of Coolgardie Railway Station (Fig. 1). Here a roughly circular depression in the Precambrian crystalline com-

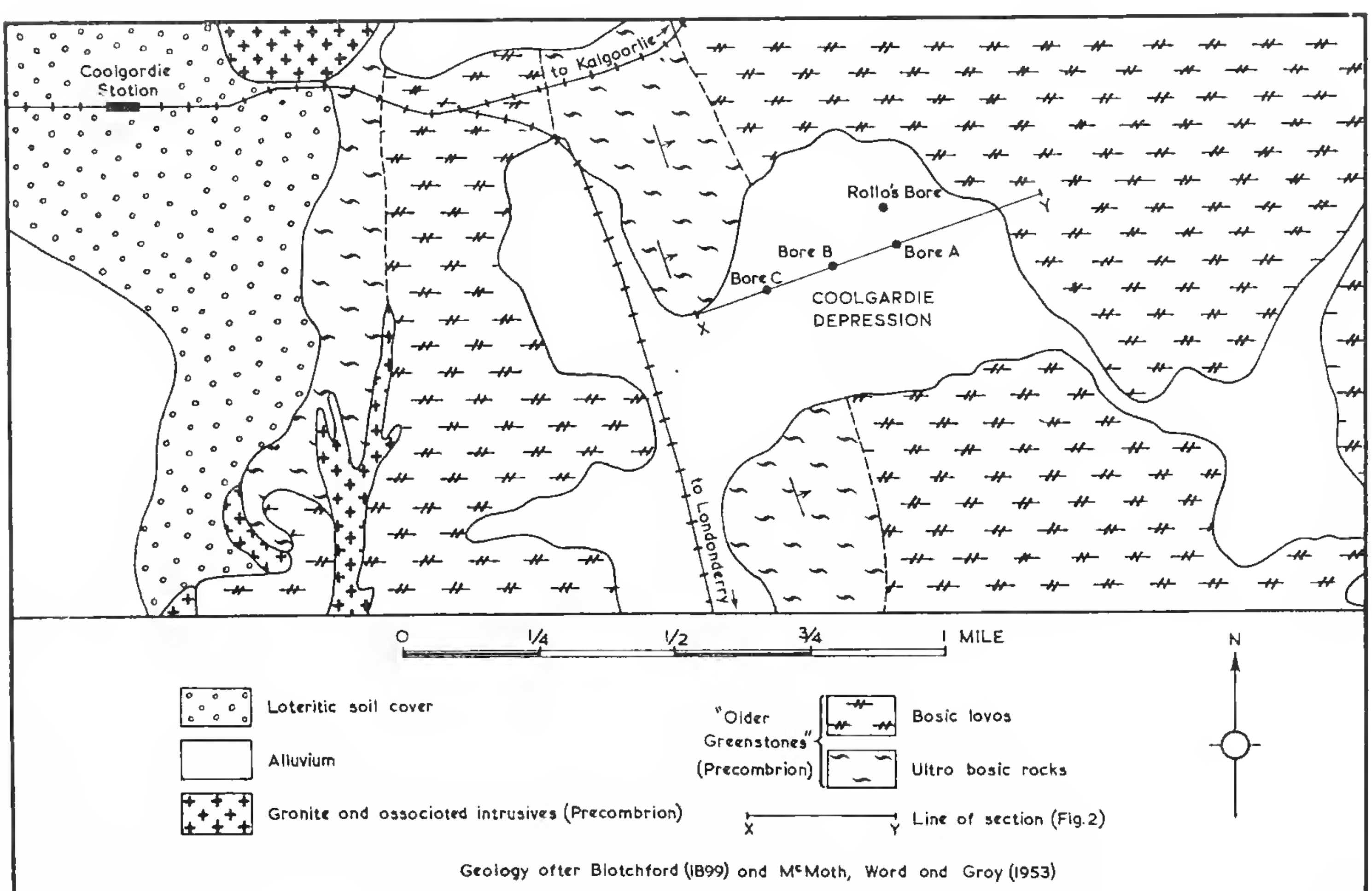


Fig. 1

plex, little more than half a mile across, is occupied by a sedimentary sequence having a maximum known thickness of 400 feet. The existence of this minor basin has been recognized since the earliest days of gold mining at Coolgardie, and between 1892 and 1897 a number of bores were sunk in the area. Rollo's Bore, situated about 1½ miles east of Coolgardie Railway Station was the deepest of these, and passed through 400 feet of more or less carbonaceous strata before entering ultra-basic metasediments. Exploitation of "deep leads" at Kanowna and Siberia encouraged further drilling in the neighbourhood of Rollo's Bore, and between 1897 and 1900, an additional series of boreholes was sunk to test the depth and distribution of the sediments. Logs of these bores were published by Campbell (in Maitland, 1901), together with a generalized map and section of the basin. Reconstructions of the sections in these bores are shown in Fig. 2, and Fig. 3 is a modification of Campbell's section.

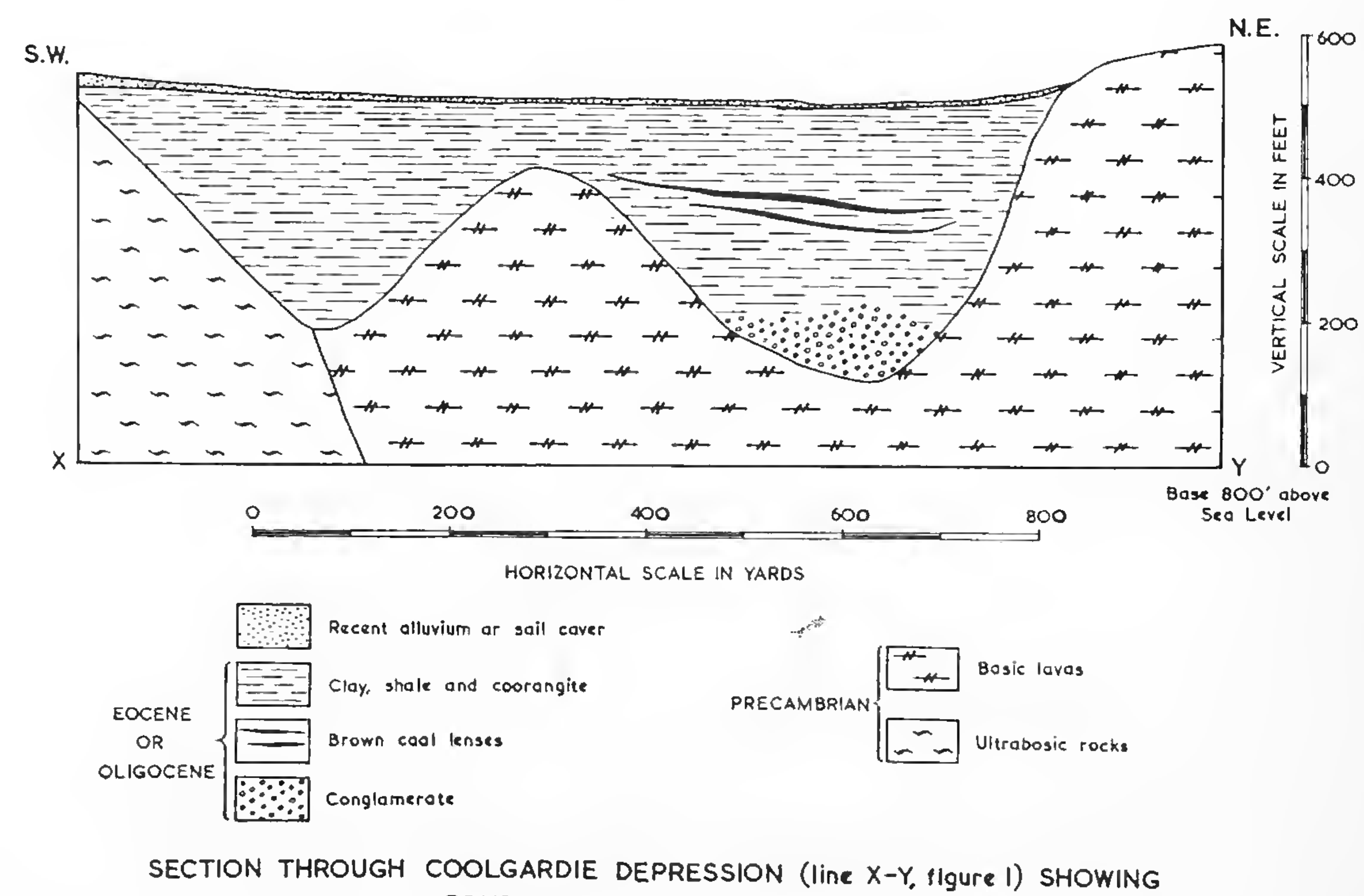
Available information from borehole logs suggests a fairly steep-sided depression, the deepest parts of which lie along its northern and western margins. The slope of the basement on the south-western side appears to be more gradual than on the northern and western margins, and the log of Bore B implies the presence of a central elevation rising about 200 feet above the floor of the depression.

Blatchford (1899, p. 22) gave a detailed section of the strata encountered in Rollo's Bore, and this is reproduced in Fig. 2.

The occurrence of brown coal in the borehole aroused interest at the time and led to some further unsuccessful prospecting in the vicinity. The shaft on Olsen's Claim, for example, was apparently sunk in an attempt to exploit the brown coal deposits. Its precise position is uncertain, but said by Simpson (1899, p. 58) to be "near Rollo's Bore". Speculation as to the age of the carbonaceous sediments also occurred in the early part of the present century. Blatchford recorded fossil leaves, some of which he assigned to the Eucalypti, from a depth of 380 feet in Rollo's Bore, and considered these to be of late Tertiary or Recent age. *Dryandra* was identified by Simpson (1902, p. 54) from the shaft on Olsen's Claim, and taken by him to indicate a Pleistocene age for the deposits. Two years later, however, Montgomery (1905) spoke of the "piece of deep ground probably of Tertiary age or even older near Colreavy's Dam". There is a curious reference, also, in Maitland (1907), to the presence of lateritic debris in a bed containing fossil Eucalypt leaves, in a bore on Government Reserve 23 near Coolgardie. This almost certainly refers to Rollo's Bore, and Maitland advocated a pre-Tertiary age for the laterite on the basis of his correlation between the Eucalypt-bearing beds and the Older Gold Drifts of Victoria.

We have been unable to locate any specimens of entire leaves from the Coolgardie sediments. Sketches of some of the leaves are, however, in the library of the School of Mines, Kalgoorlie.

FIGURE 2.



SECTION THROUGH COOLGARDIE DEPRESSION (line X-Y, figure 1) SHOWING CONFIGURATION OF BASEMENT

These were kindly made available to the authors by Mr. W. M. Cleverly, Lecturer in Charge of the Geology Department of the School of Mines. The drawings are not very satisfactory but one of them, almost certainly, is of a specimen of *Nothofagus* sp.

During the past fifty years most authors, when they have committed themselves, have accepted Blatchford's estimate of a late Tertiary or sub-Recent age for the Coolgardie sediments.

Samples Studied

A recent reorganization of the collections of the West Australian Museum brought to light three samples of sediments collected from Rollo's Bore and the immediately adjacent Rollo's Shaft. These were submitted for examination to the Department of Geology, University of Western Australia, by the Museum Director (Dr. W. D. L. Ride). Only two of the samples were marked with sampling depths, although these apparently came from fairly widely spaced horizons in the borehole. Subsequently, another sample from the Coolgardie depression was made available to the authors by the Government Geologist of Western Australia (Mr. H. A. Ellis). This specimen, a fragment of boghead coal, came from Olsen's Claim and has been analysed and described by Simpson (1899). Details and brief descriptions of the four samples studied are given below.

Geol. Survey of Western Australia. Specimen No. 1087

Locality: Olsen's Claim, Coolgardie

Depth: 65 feet

Dark brown, tough, low-rank, boghead coal with a waxy lustre and conchoidal fracture. The material was difficult to ignite, but burnt slowly with a petroliferous odour when held in a bunsen flame.

W.A. Museum Specimen No. 11987

Locality: Rollo's Bore, Coolgardie

Depth: 150 feet

Brown coal, supplied in fragments, varying between 1 cm-5 cm in diameter. Some fragments were lignitic, representing single coalified pieces of wood, and others earthy, consisting of finely macerated plant debris. Most lumps contained small quantities of microscopic pyrite, and traces of compaction slickensiding were sometimes present. The ash content was high in most fragments, although some appeared to be almost devoid of mineral matter.

W.A. Museum Specimen No. 11984

Locality: Rollo's Shaft, Coolgardie

Depth: Probably 390 feet

Black, low-rank, boghead coal, with narrow intercalated bands of carbonaceous, micaceous, shale. Fragmentary leaf impressions were fairly plentiful, but too poorly preserved for reliable identification, and occasional lentoid bands of protovitrite occurred in both the boghead coal and shale partings.

The sample burnt fairly readily with a strong petroliferous odour, and is no doubt the material Montgomery (1905) called the "Coolgardie oil shale". Montgomery recorded a number of proximate analyses of samples from Rollo's Bore, although he gave no depths for the specimens examined. A typical analysis, taken from Montgomery's figures, was as follows:

H_2O 18.32%, V.M. 23.65%, F.C. 10.57%, Ash 47.46%.

Montgomery was not impressed by the possibility of exploiting the deposit as a fuel.

W.A. Museum Specimen No. 11986

Locality: Rollo's Shaft, Coolgardie

Depth: unspecified

Dark brown, low-rank, boghead coal. The sample closely resembles specimen 11984 in its physical properties, except that it contains less visible mineral matter.

Palynological Results

The humic material in all samples was readily soluble in hot 10% sodium hydroxide without prior oxidation, and plant microfossils were plentiful in the washed residues. Treatment with hydrofluoric acid was necessary to remove finely dispersed silicates.

Representative slides from the four samples discussed here are retained in the collections of the Department of Geology, University of Western Australia (Slides Nos. 41618 to 41621 incl.).

Undescribed species were present in both microfloras, but the majority of the forms observed are well known from Tertiary sediments in southern Australia, New Zealand and Antarctica. Descriptions of these species may be found in the papers of Cookson and her co-workers, and in the monograph by Couper (1953). The taxonomy of the undescribed forms will be treated by one of the present authors (D.M.C.) in a future publication.

Microfloral Lists

Specimen No. 1087. Depth: 65 feet.

Angiospermae:
- *Nothofagus* sp.—Abundant
- *Casuarinidites cainozoicus* Cookson and Pike—Common
- *Triorites harrisii* Couper—Rare
- *Cupanieidites orthoteichus* Cookson and Pike—Rare

Algae:
- *Croococcus* sp.—Abundant

Specimen No. 11987. Depth: 150 feet.

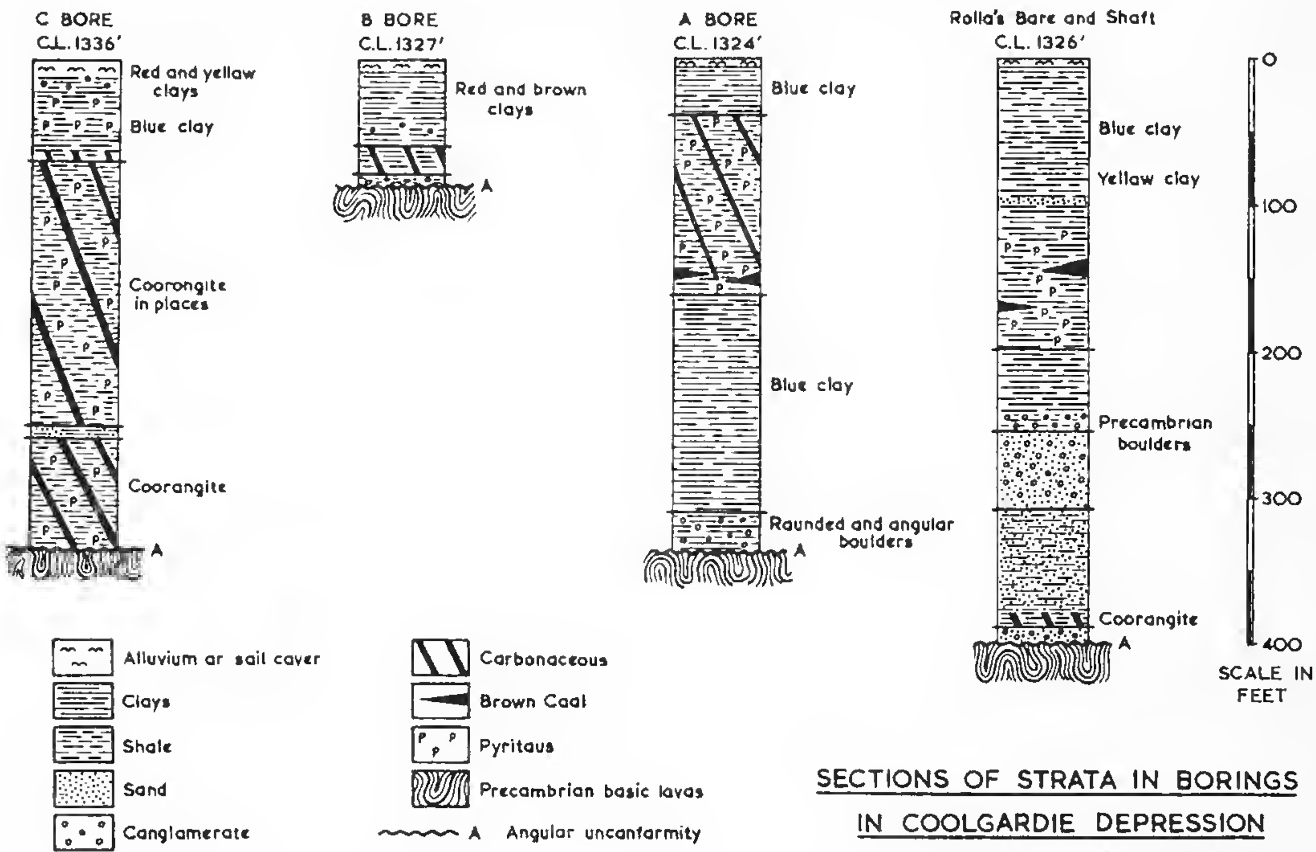
Angiospermae:
- *Nothofagus* at least two species.—Abundant
- *Triorites harrisii* Couper—Common
- *Beaupreaidites verrucosus* Cookson—Rare
- *Casuarinidites cainozoicus* Cookson and Pike—Very rare
- *Myrtaceidites parvus* forma *anesus* Cookson and Pike—Rare
- *Proteacidites* sp.—Very rare
- *Tricolpites* sp.—Very rare

Gymnospermae:
- *Dacrydium florinii* Cookson and Pike—Rare
- *D. mawsonii* Cookson—Rare
- *Microcachryidites antarcticus* Cookson—Rare
- *Podocarpidites* sp.—Rare

Cycadales:
- *Monocolpopollenites* sp.—Rare

Filicales:
- *Gleichenia circinidites* Cookson—Common
- *Cyathidites* cf. *C. minor* Couper—Rare

FIGURE 3.



SECTIONS OF STRATA IN BORINGS IN COOLGARDIE DEPRESSION

Compiled from Blatchford (1899) & Campbell (1901)

Specimen No. 11984. Depth: Probably 390 feet.

Angiospermae:
- *Nothofagus* at least two species.—Common
- *Triorites harrisii* Couper—Rare
- *Beaupreaidites verrucosus* Cookson—Rare
- *Tricolpites* sp.—Rare

Gymnospermae:
- *Dacrydium florinii* Cookson and Pike—Rare
- *D. mawsonii* Cookson—Rare
- *Microcachryidites antarcticus* Cookson—Rare
- *Podocarpidites* sp.—Rare

Filicales:
- *Gleichenia circinidites* Cookson—Very rare

Algae:
- *Botryococcus braunii* Kutz.—Common

Specimen No. 11986. Depth: unspecified.

Angiospermae:
- *Nothofagus* at least three species—Common
- *Triorites harrisii* Couper—Common
- *Myrtaceidites parvus* forma *anesus* Cookson and Pike—Rare
- *Banksia* sp.—Rare
- *Proteacidites annularis* Cookson—Rare
- *Cupanieidites orthoteichus* Cookson and Pike—Rare

Gymnospermae:
- *Dacrydium florinii* Cookson and Pike—Rare
- *Microcachryidites antarcticus* Cookson—Rare
- *Podocarpidites* sp.—Rare

Filicales:
- *Gleichenia circinidites* Cookson—Rare

Lycopodiales:
- *Lycopodium* sp.—Rare

Algae:
- *Botryococcus braunii* Kutz.—Abundant

Significance of Microfloras

Certain quantitative differences are apparent in the compositions of the microfloras listed. Coniferalean pollens, for example, are most plentiful in the assemblage from 390 feet, which contains also a great deal of fragmentary algal debris. The abundance of *Nothofagus* spp., however, is a feature of each microflora, and this fact, taken in conjunction with their close qualitative similarity, strongly suggests that the four assemblages were derived from essentially similar floras. Minor climatological and geographical factors can undoubtedly be invoked to explain the quantitative differences mentioned above, and it seems certain that no great time interval is represented by the sediments in the Coolgardie depression. It may be concluded, therefore, that the four samples under discussion are of much the same geological age.

The species listed all have long vertical ranges in the Australian Tertiary, and individually do not allow a precise dating of the deposit. A more refined correlation may be attempted if the Coolgardie assemblages are treated as a single palaeobotanical unit.

Comparable microfloras are found in lignites which occur in the Plantagenet Beds at isolated places along the south coast and in the Pidinga Bore on the eastern margin of the Eucla Basin. The microfloras from lignites at Denmark and Nornalup were described by Cookson (1954), and correlated by her with Microflora C from the Lower Tertiary of Victoria. This correlation was based on the presence of *Proteacidites pachypolus* in lignitic clays from a depth of 50 feet in a bore near Denmark. The same species has also been described from the Pidinga lignites (Cookson and Pike, 1954).

Proteacidites pachypolus has not, however, been found in lignites from the Plantagenet Beds

TABLE I

The distribution of some plant microfossils in Lower Tertiary deposits in South-Western Australia

Species	Localities			
	Denmark	Nornalup Lignite	Esperance Lignite	Coolgardie Beds
Dinoflagellata:				
Wetzeliella lineidentata Deflandre & Cookson	+	—	—	—
Palaeohystrichophora cf. *spinosissima* Deflandre	+	—	—	—
Hystrichosphaeridaceae:				
Hystrichosphaera cf. borussica Eisenack	+	—	—	—
Hystrichosphaeridium floripes Deflandre & Cookson	+	—	—	—
H. inodes subsp. *gracilis* Eisenack	+	—	—	—
Pterospermopsidaceae:				
Pterospermopsis microptera Deflandre & Cookson	+	—	—	—
Pterocystidiopsis velata Deflandre & Cookson	+	—	—	—
Xanthophyceae:				
Botryococcus braunii Kutz.	—	—	—	+
Myxophyceae:				
Chroococcus sp.	—	—	—	+
Filicales:				
Cyathidites cf. *C. minor* Couper	—	—	—	+
Gleichenia circinidites Cookson	—	—	—	+
Lycopodiales:				
Lycopodium sp.	—	+	—	+
Cycadales:				
Monocolpopollenites sp.	—	+	—	+
Coniferales:				
Dacrycarpites australiensis Cookson & Pike	+	—	—	—
Dacrydium florinii Cookson & Pike	+	+	+	+
D. mawsonii (Cookson) Cookson	+	+	+	+
Microcachryidites antarcticus Cookson	—	+	+	+
Podosporites micropteris (Cookson & Pike) Balme	—	+	+	?
Podocarpidites ellipticus Cookson	+	+	+	+
Angiospermeae:				
Nothofagus spp.	+	+	+	+
Triorites harrisii Couper	+	+	+	+
Beaupreaidites verrucosus Cookson	—	+	—	+
Tricolpites sp.	—	+	—	+
Casuarinidites cainozoicus Cookson & Pike	+	+	+	+
Cupanieidites orthoteichus Cookson & Pike	+	+	—	+
Santalumidites cainozoicus Cookson & Pike	+	—	—	—
Myrtaceidites parvus forma *anesus* Cookson & Pike	+	+	+	+
M. eucalyptoides Cookson & Pike	—	—	—	+
Banksieaeidites sp.	+	+	+	+
Proteacidites annularis Cookson	+	+	+	+
P. crassus Cookson	+	+	—	—
P. grandis Cookson	+	—	—	—
P. pachypolus Cookson & Pike	+	—	—	—
P. adenanthoides Cookson	—	+	+	+

at Nornalup, Esperance and Fitzgerald River. These occurrences are all higher in the sequence than the Denmark clays, and are, therefore, of younger age. The absence of *P. pachypolus* from the Coolgardie assemblages, together with their gross similarity to those from the younger south-coast lignites (see Table 1) suggest that the Coolgardie sequence may be correlated with part of the Plantagenet Beds. It is considered, therefore, that the Coolgardie beds are of Upper Eocene or Lower Oligocene age.

Origin of the Coolgardie Sediments

The Basement Depression

The strata in Rollo's Bore represent the thickest single section of Tertiary sediments known in that area of Western Australia lying between the Darling Fault Zone and the western margin of the Eucla Basin. In view of the small surface area of the Coolgardie deposits, such a sedimentary thickness is remarkable, and some authors have been reluctant to accept the depression as an erosional feature. Montgomery (1916, p. 93) suggested that it was of tectonic origin, and his view was accepted by Jutson (1934, p. 287), who named the sedimentary area the Coo*lgardie Sunkland*. No positive evidence in favour of a tectonic origin can be put forward however, and such an explanation appears to create more difficulties than it solves.

There is no need to invoke tectonic deformation in order to explain the sedimentary thickness. Local base levels in the "deep leads" at Kanowna, which are accepted by all authorities as buried watercourses, are almost identical with those in the Coolgardie depression. Recent refraction seismograph surveys (Urquhart, 1956) have been interpreted to indicate even lower base levels in V-shaped basement valleys in the Kalgoorlie area. Examples of similar "deep leads" are to be found throughout the goldfields areas, and Clarke (1934, unpub. data) regarded them as the infilled remnants of an earlier drainage system.

Too little sub-surface information is available to enable the basement contours of the Coolgardie basin to be constructed with any confidence. However, the existing data suggest the presence of a deep, steep-sided channel skirting the western and northern margins of the depression. The basin floor slopes more gently from the south-western margin, and the

basement elevation apparent in Bore B (Fig. 3) may represent a spur projecting from the southern edge of the basin. Such a basement configuration could be interpreted as the remnant of an incised meander.

A difficulty certainly arises if the basin is regarded as a product of fluvial erosion, in that no obvious continuation of the valley is apparent in the adjacent crystalline rocks. Maitland (1897) reported considerable thicknesses of valley-fill deposits in the neighbourhood of Coolgardie, but as far as can be judged from his report, the nearest of these is three or four miles to the south-east of Rollo's Bore. A continuation of the depression may exist as a narrow channel under the cover of surface alluvium and laterite, and, if so, could probably be detected only by geophysical means.

An alternative explanation is that the basin is of glacial origin, and, if so, it may date back to Sakmarian times. Such a postulate probably necessitates the acceptance of redistribution of pre-existing sediments by the advancing sea, in Middle or Upper Eocene times. Deposition of the existing sediments would then have begun in a coastal lake following the retreat of the sea from the Coolgardie area. It is interesting to note that Campbell (1906) suggested many years ago that the Lake Cowan depression was of glacial origin. This view was rejected by Jutson (1934), who believed that basement irregularities which contain the "deep leads" were formed during a period of uplift which post-dated the Tertiary marine transgression.

One of the important things to emerge from this investigation is the confirmation of the views of Montgomery (1916) and Clarke (1934, unpub. rep.) that at least some of the "deep leads" were formed in depressions which were already in existence at the time of the Eocene transgression. This is now known to be true of the Coolgardie depression and the Princess Royal Lead at Norseman. It would be surprising if it did not hold for many other similar deposits in the eastern goldfields.

Environment of Deposition of the Sediments

From their high organic content and the frequent occurrence of pyrite, it cannot be doubted that the majority of the sediments in the Coolgardie depression were formed under anaerobic, reducing conditions. Obviously, also, the surface waters were at times highly productive to enable the accumulation of the enormous numbers of microscopic algae which provide the source of hydrocarbons in the boghead coal or "oil shale". Stratification of the body of water may, therefore, be inferred, and this was apparently thermally controlled. Such conditions characterise the lacustrine environment, and the sections of strata given by Blatchford and Campbell provide a good example of the infilling of a basin by lacustrine sediments. The section in Rollo's Bore begins with sands and occasional boulders, and passes into oil shale and clays with lignites in the upper part of the succession.

Little can be deduced from the composition of the microfloras, as to the salinity of the water during the deposition of the sediments. Variations in salinity appear to favour the growth of a multiplicity of blue-green algae, and the best known deposits of present day coorongite are forming in salt lakes along the southern coasts of South and Western Australia. Nevertheless it is unwise to press such an analogy, for many genera of the Chlorophyceae show a wide tolerance to salinity.

On general palaeogeographic grounds it seems certain that the Eocene sea must have reached at least as far north as Coolgardie during its maximum transgressive phase. Marine sediments which are now correlated with the Plantagenet Beds (Singleton, 1954; McWhae, Playford, Lindner, Glenister and Balme, 1958), occur about 80 miles south-east of Coolgardie, in the vicinity of Lake Cowan and Norseman. These sediments contain beds of spongolite which almost certainly were formed in water of considerable depth (Hinde, 1910). Clarke, Teichert and McWhae (1948) suggest that in the south-eastern part of Western Australia relative sea-level was 1,500 feet higher during the Tertiary transgression than it is at present. This is very nearly the level of present topographic highs in the Coolgardie district.

No carbonates have been recorded from any of the Coolgardie bores, although Campbell reported gypsum crystals from Bore C. These probably represent secondary sulphates resulting from the interaction of $CaCO_3$ and H_2SO_4. Free sulphuric acid, a product of the decomposition of pyrite, is present in bore waters from the neighbourhood of Rollo's Bore (Blatchford, 1899, p. 46). Water from Rollo's Bore itself is highly saline and suitable for drinking only after condensation.

Indirect evidence suggests, therefore, that the Rollo's Bore sediments were deposited in a small saline coastal lake, although a fresh water origin could not be convincingly refuted. In either case there seems no doubt that deposition was initiated by epeirogenic down-warping during the Lower Tertiary. Aggradation would then have taken place either along the coast following a period of drowning and dune formation, or in a freshwater lake formed by the ponding of a river as a result of down-warping in its middle course.

The presence of well-preserved microfloras in sediments of the deep lead type at Coolgardie suggests that palynological studies may prove a useful technique in attacking physiographic problems in Western Australia. It seems, for example, that many of the present topographic patterns may be controlled by an erosional cycle of much greater antiquity than many authors have supposed. There is a wide field for investigation, and as a preliminary, an examination of the carbonaceous sediments at Mt. Kokeby (Feldtmann, 1919) would be of considerable interest.

Acknowledgments

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5.—Topographic Relationships of Laterite near York, Western Australia

By M. J. Mulcahy*

Manuscript received—17th March, 1959

In the course of field studies of soils in an area extending eastwards from the Avon Valley, Western Australia, a number of erosional and depositional surfaces have been recognized. The older of these surfaces are lateritic. This paper presents an account of the distribution and relationships of the surfaces, and suggests a relative chronology for them. The soils associated with each surface are only briefly mentioned, as their characteristics will be reported in greater detail elsewhere.

The area studied is that shown in Fig. 2. The town of York, which lies in the southwest corner is 60 miles east of Perth. The country rocks are the Precambrian granites and gneisses of the West Australian Shield, with occasional basic intrusions (Wilson 1958). The general pattern of the drainage is controlled by the geological structure, and the main streams are the north-flowing Avon River, the south branch of the Mortlock River flowing northwestwards across the area to join the Avon, near Northam, and the south-flowing salt lake system east of Quairading.

The climate is of the Mediterranean type, with hot dry summers, most of the rain falling during the winter. At York, the average annual precipitation is 18 in., falling to 13.5 in. at Jennaberring, just beyond the eastern boundary of the area†.

It appears that the dominant process of slope formation has been by parallel scarp retreat, giving typical "breakaway" country. To a considerable degree, the erosional products of the breakdown of the lateritic surfaces have been removed from the system. This means that, in contrast to the higher rainfall country of the Darling Range to the west, the lateritic surfaces are sharply defined by topographic features. In the wetter country, on the other hand, though the landscape is deeply dissected, lateritic detritus in the form of yellow sands, ironstone gravels and boulders mantles most of the slopes and many valley floors. Often, too, this detrital laterite (Woolnough 1927) is recemented with iron oxides into massive pavements, rendering the various surfaces difficult to recognize.

For convenience, each surface in the area studied has been named, using appropriate local place names. The detailed field relationships of the surfaces recognized are shown in Fig. 1.

The *Quailing* surface occupies the highest parts of the landscape, and carries what may be presumed to be the oldest laterite. The surface soil is a yellow sand or sandy loam over ferruginous concretions, which in turn overlie the usual mottled and pallid zones, the latter being of the order of 15 feet deep. Massive laterite pavements are relatively limited in extent, occurring mainly along the breakaway edges or at the crests of slight rises. Work carried out in association with the University of Western Australia indicates that the surface yellow sands and the ferruginous concretions beneath them contain appreciable amounts of easily weatherable minerals (Morgan and Herlihy 1956) which are almost completely absent from the underlying pallid zones, though present in the parent rock. It appears, therefore, that with the formation of the ironstone, inclusions of only partly weathered rock may be protected from further weathering, and these inclusions can occasionally be observed in the field. Further, apart from slight organic staining, the surface yellow sand shows no profile differentiation, though bleaching of the sand grains to give a grey A_2 horizon would be expected to take place fairly quickly. It is therefore suggested that although the Quailing surface is old, the soil developing thereon is relatively young, and that its parent material is the ferruginous horizon of the Quailing laterite.

Downslope from the Quailing erosional surface are accumulations of deep yellow sand with some soft, round, reddish brown mottles, which, as Prider (1946) has suggested, may be ferruginous concretions in the course of formation. The soils otherwise show an undifferentiated profile, with the same assemblage of easily weatherable minerals as in the laterite above. The deep yellow sands are therefore considered to be a colluvial deposit derived from the erosion of the Quailing surface, and the corresponding erosional and depositional surfaces are shown in Fig. 1.

The *Kauring* surface generally lies about 20 feet below the level of the Quailing erosional surface, occupying wide, flat-floored valleys cut in the latter. The soil is a grey sand overlying a massive ironstone, paler than that of the Quailing surface, and has been occasionally observed to carry inclusions of kaolinised rock. Normal pallid zone clays lie beneath. In contrast to the Quailing sands, these grey sands contain very few easily weatherable minerals. This soil therefore, appears to correspond with the intact laterite profile such as the Eleanor sand described by Northcote (1946) from Kangaroo Island, but it is to be noted that it occupies the floors of shallow valleys cut in the Quailing surface, while the inclusions of pallid zone in the ferruginous horizon indicate formation in already weathered material. It is concluded, therefore, that the Kauring laterite is younger than the Quailing laterite.

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† Book of Normals, Commonwealth Meteorological Branch.

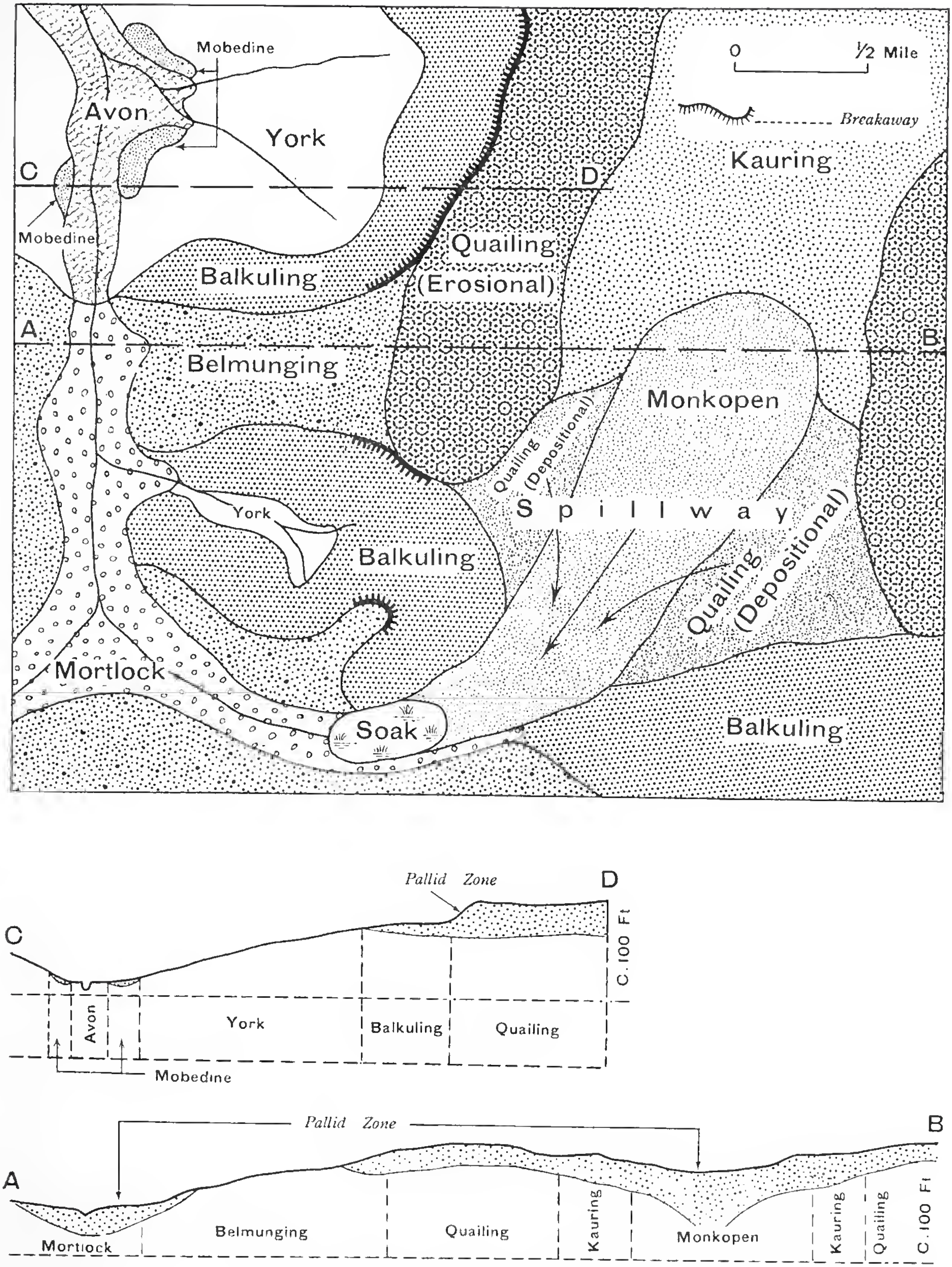

Fig. 1.—Detailed distribution of the surfaces.

The *Monkopen* surface occupies deep sandy hollows originating at high level in the Kauring surface. The sands are grey at the surface, becoming pale yellowish brown with depth. The texture may rise to sandy loam with some small ferruginous concretions at about three feet, and this horizon may be waterlogged in winter, in contrast to the soils of the surfaces already described. At depth the material resembles the Quailing yellow sands. As shown in Fig. 1, the Monkopen surface sweeps down from high level, passing through gaps in the line of breakaways like a sandy avalanche, being joined by the yellow sands from the Quailing surface on route. Thus, the features together have been referred to as "spillways" and particle size studies show that the material has been transported. The sorting coefficient of the sand (Twenhofel and Tyler 1941) near the top of the spillway is 2.0 decreasing to 1.4 at the bottom. This indicates that the sands in the lower positions are more sorted, and therefore must have moved farther than those above. They commonly end in soaks which are often permanent supplies of good quality water. The depth of the sand varies, tending to be deepest, 50 feet or more, towards the centre of the spillway. Evidence from bores and wells shows that there may be more than one band of ferruginous concretions, possibly indicating a number of depositional periods separated by soil forming periods. The Monkopen and Quailing sandy deposits usually overlie pallid zone material, but they occasionally overlie other soils as will be described below.

The "Old Plateau" of Western Australia (Jutson 1950) has been regarded by a number of workers (Woolnough 1927, Prescott 1952, Stephens 1946) as having been formed during one or more epochs of the Tertiary. The evidence presented here suggests that the oldest surfaces, i.e. the Quailing and Kauring surfaces, represent this Tertiary laterite of Western Australia, which thus appears to have formed in two stages. It has undergone considerable modification as evidenced by the Monkopen depositional material which has not been carried out of the system, and further, this kind of modification has continued up to fairly recent time, resulting in the stripping of the Quailing surface and the deposition of the yellow sand below it. The surfaces now to be described represent the sides and floors of valleys formed by the erosion of the "Old Plateau".

The Quailing and Kauring surfaces, except where breached by spillways, are in general bounded by a break in slope. Where the break is a minor one it forms the upper limit of the *Belmunging* surface (Fig. 1) which extends as lateritic spurs and ridges sloping at an angle of 2° or steeper, down towards the drainage lines. The soil consists of a greyish brown sand with ferruginous concretions over a reddish brown and yellowish brown mottled clay which hardens when exposed in ditches and cuttings. The pallid zone is commonly absent except at the down slope limit, the profile passing into the country rock at about 8 feet.

Downslope the Belmunging surface gives way to flat valley floors forming the *Mortlock* surface. The soils here are similar to those of the Belmunging ridges though less well drained and with greyer colours in the surface. Beneath the ferruginous zone there is, however, an appreciable though variable depth of pallid zone often

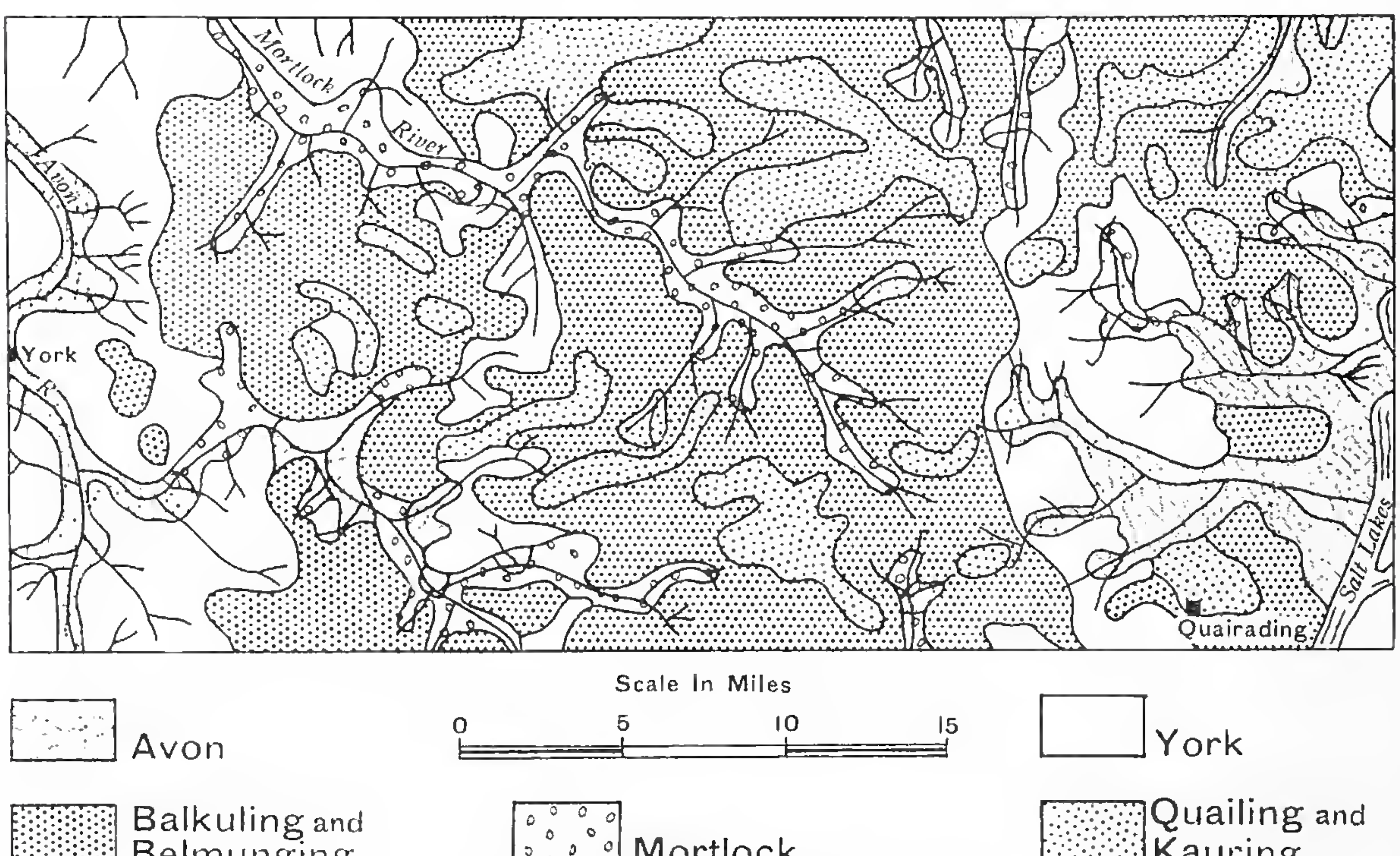

Fig. 2.—General distribution of the surfaces.

recognizable as a kaolinised coarse water-laid sediment. Thus the Belmunging and Mortlock surfaces represent the sides and floors of old valleys cut in the Tertiary surface. (Fig. 1, Section AB.)

The destruction of the Quailing, Kauring and Belmunging surfaces is proceeding by the retreat of scarps which are actively eroding at the present day. The scarps are the breakaways which are such a feature of this and other parts of Western Australia, and have been already described by many workers, e.g., Walther (1915). The pediment, which slopes away at an angle of about 1° or more from the foot of the breakaway, is essentially a cut surface (King 1949); in this case cut in pallid zone or weathered rock (see Fig. 1, Section CD), and has been named here the *Balkuling* surface. The soils are pale greyish or pinkish clays, often overlain by a greyish brown quartzose sandy and gritty pedisediment, decreasing in depth with distance down the slope. Where it adjoins a spillway the Balkuling surface can be seen to pass under and to be buried by the yellow sand of the Quailing depositional surface, and occasionally by the grey sand with an ironstone gravel horizon of the Menkopen surface. Thus it predates the former, and part at least of the latter deposit.

Below, the lower limit of the Balkuling surface is marked by a slight increase in slope, which is also the upper limit of the *York* surface. This is characterised by outcrops of unweathered rock, with associated shallow skeletal soils, and, particularly in the Avon Valley, by deeper soils consisting of brown sandy loams over reddish brown clays, with fresh rock fragments throughout the profile. The latter, though usually non-calcareous, are the so-called red-brown earths of Prescott (1931), and later Teakle (1938). The soils of the York surface have not been intensively studied, and may, in fact, judged by the criteria of Butler (1958), consist of a complex of surfaces of different ages. Nevertheless, the distribution of the York surface in proximity to active drainage lines suggests that the complex as a whole represents a cycle of erosion cutting into the Balkuling and Belmunging surfaces. The depositional material of the valley floors associated with the York surface has been called the *Avon* surface, and carries brown and grey fine textured calcareous soils, the solonised brown and solonised grey soils of Teakle (1938). However, in all the valleys examined the solonised grey and brown soils overlie kaolinised coarse waterlaid sediments which appear to be the eroded stump of the Mortlock lateritic surface. Thus the Avon and York surfaces are established as being younger than the Mortlock and Balkuling, and hence the Belmunging surfaces.

It remains to mention one further feature, namely, the *Mobedine* surface. This appears to be confined to the Avon Valley, where it is found at or about the 600 foot contour from near York downstream to beyond Toodyay, a distance of about 50 miles. It occurs as a scree forming the noses of ridges as shown in Fig. 1. Each rock fragment, however, has a coat of iron oxide, which in some instances cements the material into massive laterite-like boulders. It may overlie reddish brown and yellow mottled clays resembling the subsoils of the Belmunging surface, or relatively fresh rock. Its age remains uncertain at the moment, though it is tempting to suggest that it lies somewhere between the Belmunging and York surfaces.

The general distribution of the surfaces over the whole area is illustrated in Fig. 2, and it is again apparent that their pattern of occurrence is closely controlled by the erosional history. The latest erosional cycle recognized has worked headwards up the Avon Valley and its tributaries, stripping the Belmunging surface from the valley sides, while the stumps of the Mortlock surface are buried in the valley floors. Beyond the limits of this cycle the Belmunging surface dominates the valley slopes. The Quailing and Kauring surfaces occupy the divides, and the Balkuling surface is extending by headward erosion at the expense of the three older surfaces.

The distribution of the older surfaces in relation to the drainage system of the Avon to the west, and the salt lakes beyond Quairading to the east, and the fact that on the regional as well as the local scale the Quailing and Kauring laterites dip towards the drainage lines suggests that even as far back as Tertiary times these drainage systems or their precursors were in existence. Subsequently, the Belmunging and Mortlock surfaces, so well preserved in the present Mortlock River valley flowing northwestwards across the area, were formed. The map (Fig. 2) shows that the latest cycle of erosion recognized, that responsible for the York erosional surface and the Avon depositional surface has to some extent invaded the catchment of the Mortlock system both from the east and the west.

The York cycle is working back, however, not only from the Avon Valley, which drains to the sea, but also from the tributaries of the Mortlock, upstream of the Mortlock surface, and from the head waters of the distributary streams which feed the salt lake systems to the east. While epeirogenic uplift may account for the first case, that of the Avon Valley, it cannot account for the latter two, which are working to local base levels. Thus some other factor, possibly a climatic one, must be involved. According to Penck (1953) an increase in rainfall may increase rates of down cutting by streams, but the widely distributed remnants of the Mortlock layer in the valley floors preclude this explanation. On the other hand, the work of Butler (1958) correlates instability of slopes with arid conditions and does not necessitate the removal of the older deposits in the valley floors, but rather their burial by younger sediments.

It is hoped to extend similar studies of the relationship of soils and land surfaces to representative areas of southwestern Australia, and correlation with the depositional systems and soils of the Swan Coastal Plain, for which McArthur and Bettenay (in press) have suggested an absolute chronology, may be possible. Thus may be achieved an understanding not only of the erosional history but also of one of the main factors governing the pattern of distribution of the soils.

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6.—The Status of Yarra singularis and Geotria australis (Petromyzontidae)

By R. Strahan*

Manuscript received—18th November, 1958

Extensive references to publications on the lampreys of the Southern Hemisphere may be found in Regan (1911) and Whitley (1932, 1940). In this paper, reference is made only to those authors whose opinions have radically affected the taxonomy of the group.

The name *Yarra singularis* was given by Count F. de Castelnau in 1872 to a single ammocoete from the Yarra River, Victoria, Australia. He described it as follows: "The body is eel-shaped, naked, cylindrical and elongate, being 23 times as long as high. It is entirely divided into annular rings, which appearance seems to be due to the muscular flakes being very visible through the smooth skin. I can see no teeth, the upper lip is flat and considerably prolonged over the buccal aperture; it is truncated in front and this part seen upperly is rather bifurcated. The lateral line is well-marked in all the length of the body; there is only one dorsal fin, which begins at about two-thirds of the length of the body and is joined with the caudal and anal fins; the latter is considerably shorter than the dorsal. No eye visible. The skin of the throat is rather extensible; the prolongation of the upper lip over the lower is equal to the height of the body. The tail is pointed. The colour is of light green with the belly white; on the back extends a narrow longitudinal line; the head and throat are pink and the fins of the same colour." It was 11 cm long.

Castelnau's first impression was that he had an ammocoete of *Geotria australis* Gray but, because he had seen a specimen only 8 cm long which had more adult-like characteristics, he rejected the assumption on the ground that the more juvenile form could not have been larger than the more mature form. This reasoning is invalidated by the fact that lampreys suffer a reduction of size during metamorphosis.

Gray (1851) erected the genus *Velasia* for a Chilean lamprey in the British Museum, contrasting this with the Australian *Geotria*, but Günther (1870) united the two genera, reducing *Velasia* to *Geotria chilensis* (Gray). Günther also erected a new species, *G. allporti*, on the basis of a single, extremely decomposed specimen from Tasmania. The outer cusps of the supraoral lamina were described as being "finely serrated on the inner margin." I have examined the type specimen in the British Museum and find that this is due to the loss of the superficial horny cap of the lamina. The condition can be duplicated by prising off the horny layer of the lamina of a typical *Geotria australis*.

Ogilby (1896) reverted to the older distinction between *Geotria* and *Velasia*, based on characters set out in Table I.

TABLE I

Characters distinguishing Velasia from Geotria (according to Ogilby, 1896)

Geotria	*Velasia*
Body rather short and stout	elongate and slender
Head large	small
Suctorial disc very large, broader than long, extending backwards more than mid-way to the eye	very small, longer than broad, extending backwards mid-way to the eye
Outer lip rudimentary	present, continuous behind
Surface of disc smooth	plicated
Dental plates grooved	smooth
Discal teeth widely separated	approximated
Ventribasal plate of tongue bicuspid	usually tricuspid
Origin of first dorsal fin on last third of body	middle third of body
No series of pores on head or trunk	head and trunk with conspicuous series of open pores, forming a well-marked lateral line

Within the genera so separated, Ogilby erected the species, *Velasia stenostomus* Ogilby, to which he relegated part of *Geotria chilensis* of Günther, *Yarra singularis* Castelnau, and *Neomordacia howittii* Castelnau, this last-named being another genus erected on the basis of a single juvenile specimen. With respect to the latter two, Ogilby wrote: "From the size of the specimens, the insufficiency of the descriptions and the destruction or loss of the type, it will always be impossible to say whether I am justified in my conclusions or, indeed, to what species his (Castelnau's) immature and ammocoetal forms should be united. If however, the types are extant and on examination show that my identification is correct in one or other instance, Castelnau's name must necessarily have priority over mine."

Dendy and Olliver (1901), having access to a large sample of New Zealand lampreys caught at the same time in the same locality, recognised a range of forms intermediate between *Geotria australis* Gray and *Velasia stenostomus* Ogilby. They reached the conclusion that the latter were immature stages of the former, this being supported by dissection, which revealed that the pouched forms were sexually mature, whereas the unpouched forms were all immature. They therefore proposed "to call the adult form, *Geotria australis*, and to use the term *"Velasia"* to distinguish the larva . . . . it appears that, whereas the northern lampreys of the genus

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Petromyzon undergo only one metamorphosis—namely from the *Ammocoetes* to the adult—the southern form (*Geotria*) undergoes two well-marked changes, from the *Ammocoetes* to the *Velasia* and then from the *Velasia* to the adult, which latter represents a further stage in development never reached by northern forms."

Meanwhile Plate (1897) had erected a new genus and species, *Macrophthalmia chilensis* Plate, for a small, slender, striped lamprey from Chile, which he later (1902) recognised as a young stage of *Geotria chilensis* (Gray). This, as has been mentioned, was regarded by Ogilby (1896) as synonymous with *Velasia stenostomus* Ogilby which, in turn, was shown by Dendy and Olliver (1901) to be an immature form of *Geotria australis* Gray. In addition to this species, Plate (1897) recognised among the lampreys of the Southern Hemisphere, *Geotria australis* Gray, *G. stenostomus* (Ogilby), *Exomegas macrostomus* (Burmeister), and three species of *Mordacia*.

Regan (1911), recognised *Geotria australis* Gray, *G. chilensis* (Gray) and *G. stenostoma* (Ogilby), and added the new species, *G saccifera* Regan, based on a single, pouched specimen from New Zealand. *Exomegas macrostomus* (Burmeister) was placed in the genus *Geotria* as *G. macrostoma* (Burmeister).

Maskell (1929), continuing the study begun by Dendy and Olliver, clarified the situation considerably. *G. stenostoma* (Ogilby) was shown to be indistinguishable from *G. chilensis* (Gray), each therefore being equivalent to the 'velasia' stage of *G. australis* Gray. *G. macrostoma* (Burmeister) had been shown by Lahille (1915) to be indistinguishable from *G. australis* Gray, and Maskell pointed out that since the diagnosis of *G. saccifera* Regan rested on characters which varied continuously between the 'velasia' and the adult of *G. australis* Gray, it could not be accepted as a valid species. I have examined the type specimen of *G. saccifera* Regan in the British Museum and can confirm Maskell's deduction.

In the light of Maskell's revision, there thus appears to be only one species of *Geotria*—*G. australis* Gray—in the life-history of which there are four stages: (i) the ammocoete, (ii) the 'macrophthalmia', (iii) the 'velasia', and (iv) the sexually mature adult. This might appear to be a rather tenuous argument were it not for the fact that Maskell, in New Zealand, collected a complete series of such stages and intermediate forms between them. In the Warren River at Pemberton, Western Australia, I have been able to collect a similar series.

Although it would seem that the matter has been settled since 1929, Whitley (1932, 1940) has reverted to the attitude of Ogilby (1896) in placing the 'velasia' apart as a separate genus on the grounds that "It is not definitely proven that this nominal species is merely a form of *Geotria*, but Dr. Maskell's researches in New Zealand indicate that such may perhaps be the case." Whitley does not refer to the 'velasia' by Ogilby's name, but as *Yarra singularis* Castelnau, since "Most authors are agreed that *Yarra singularis* and *Neomordacia howittii* are names given by Castelnau to young *Velasia stenostomus* Ogilby, but the first name, being the oldest, must be employed for this species." Reference has already been made to Ogilby's reservations on this point and his own doubts are also indicated by a question mark against *Yarra singularis* and *Neomordacia howittii* in his list of synonyms for *Velasia stenostomus*. Subsequent authors have followed Ogilby, but without noting his reservations and their unanimity has no significance.

All that can be said on the evidence offered by Castelnau is that the position of the dorsal fin makes it unlikely that his ammocoete was that of *Mordacia*. There was not in Ogilby's time nor is there at present any way of distinguishing between the ammocoetes of *Geotria* and *Velasia* (which is understandable if the latter has no separate existence), so there is quite as much justification for placing *Yarra* with *Geotria*, in which case the name would have no priority. The existence of the genus *Yarra* thus depends upon establishing a generic difference between *Geotria* and *Velasia*. The characters upon which Whitley attempts to do this are set out in Table II.

TABLE II

Characters distinguishing Yarra from Geotria (according to Whitley, 1932)

	Geotria	*Yarra*
1.	Mouth surrounded by expansive fringes	fringes moderately developed
2.	Labial teeth well-separated	close together
3.	A large gular pouch developed by either sex	no gular sac
4.	Length up to 20 inches	length up to 24 inches
	Additional characters, Whitley (1940)	
5.	Supraoral lamina with broad lateral cusps	——
6.	Anterior tooth tricuspid	——
7.	Back uniform blackish or dark brown	back slate-colour or bluish, sides bronze, silvery on sides of head, fins yellowish or reddish with slaty margins
8.	Without green stripes	a green stripe along each side of back.

None of these distinctions is inconsistent with the belief that '*Yarra*' is an immature stage of *Geotria*, as is demonstrated in the considerations listed below, the numbered paragraphs referring to the numbered characters in the Table.

(1, 2).—It is significant that in spite of an alleged generic difference, the pattern of the teeth on the buccal funnel is the same in '*Yarra*' and *Geotria*. The wider spacing of the teeth in *Geotria* is to be expected if the buccal funnel becomes enlarged towards the end of the life-history, continuing a trend which is first manifested in the transformation from 'macrophthalmia' to 'velasia'. Many specimens can be found (there are a number in the Western Australian Museum) in which the buccal funnel is intermediate between that of a typical '*Yarra*' and that of a pouched lamprey.

(3).—A gular pouch of the size depicted in most illustrations of *Geotria* is a rarity and, as suggested by Maskell (1929), is probably an artifact of preservation. In many cases it is augmented by putrefaction. The type specimen of *G. australis* Gray was picked up on an estuarine beach where, to judge from the state

of the specimen, it had lain for some time. The type specimen of *G. saccifera* Günther, which has a large pouch, is so far decomposed as to be almost devoid of skin. One 'macrophthalmia' in my possession, which was not preserved until some five hours after its death, developed a marked gular swelling.

Pouches of 1-2 cm depth are common and present in individuals which, on the basis of length and shape of head, would be classified as *'Yarra'*. This is consistent with the view that the pouch becomes hypertrophied at the end of the life-history. Maskell (1929) found a large pouch only in males.

(4).—Pouched forms are generally shorter than unpouched forms, as is shown in Table III.

TABLE III

Comparison of average total length of pouched and unpouched lampreys of the genus Geotria and 'Velasia'
(Numbers in brackets indicate size of sample)

Source	Pouched	Unpouched
W. Australia, fresh specimens (R.S.)	60 cm (8)	66 cm (30)
New Zealand, preserved? (Maskell, 1929)	48 cm (6)	55 cm (9)
E. Australia, preserved (R.S.) ..	45 cm (11)	51 cm (11)
E. Australia, preserved (Brit. Mus.)	41 cm (4)	51 cm (4)
Argentine, preserved (Lahille, 1915)	36 cm (1)	53 cm (19)

Any reference to total length is complicated by the shrinkage of lampreys preserved in spirit or formalin. Thus, although the data of Table III suggest a difference in size between pouched lampreys from eastern and Western Australia, a definite opinion cannot be given until measurements have been made on fresh specimens from eastern rivers. It is, however, important to note that fresh pouched specimens from Western Australia fall outside the range of size given in Whitley's description.

Cotronei (1926), Hubbs (1925) and Zanandrea (1940) have shown that lampreys of the Northern Hemisphere decrease in length prior to spawning, this shortening being mainly in the caudal region and leading to a reduction in the distance between the caudal fins. Maskell (1929) has given convincing arguments for the same phenomenon in *Geotria australis*, which would dispose of Ogilby's (1896) distinction between *Geotria* and *'Velasia'* on the relative position of the first dorsal fin (see Table I), and Lahille's distinction between *G. australis* and *'G. chilensis'*, based on similar criteria.

(5).—The lateral cusps of the supraoral lamina are wider in pouched specimens and separated from the basal plate by a distinct groove. However, individuals with small pouches and only slightly expanded buccal funnels have lateral cusps of intermediate size, which are separated from the basal plate by a slight groove. It is reasonable to assume that the expansion of the lateral cusps is the result of hypertrophy of the funnel.

(6).—Whitley's statement that the anterior lingual tooth of *Geotria* is tricuspid is evidently a *lapsus*, since his figure shows two cusps. Ogilby (1896) stated that the tooth was bicuspid in *Geotria* and 'usually tricuspid' in *'Velasia'* (Table I). Lahille (1915) figured a series of growth stages in *'G. chilensis'*, depicting the change from tricuspid to a more or less bicuspid condition. Maskell (1929) showed that the condition was variable in the unpouched forms and apparently dependent upon the number of times the outer horny cap had moulted. In the 'macrophthalmia' the tooth is tricuspid and the middle cusp is the tallest of the three. In unpouched forms the middle cusp, if present, is smaller than the lateral cusps. In pouched forms it is usually absent, but may be present as a small hillock. Thus it appears that, as the lamprey grows older, the middle cusp diminishes in relative size.

(7, 8).—The distinctive coloration of unpouched specimens was described by Ogilby (1896) and is quoted in Whitley's diagnosis. The coloration is similar to that noted by Plate (1897) and Maskell (1929) for the 'macrophthalmia'. Here the body has a silvery sheen and a dark mid-dorsal line extends from the pineal region to the posterior end of the body. On either side ef the dark line are two iridescent blue-green bands which extend to the tip of the head, being interrupted over the eyes. The distal edges of the dorsal fin are bordered with dark pigment and the fins themselves are tinged pink by the contained blood. Maskell (1929) and Lahille (1915) have recorded a silvery sheen and brilliant blue-green dorso-lateral stripes in unpouched lampreys entering rivers from the sea and both Maskell (1929) and Mann (1954) are of the opinion that this bright coloration becomes obscured by degenerative changes in the skin as the animals migrate upstream. Applegate (1950) records similar reduction in the intensity of the colour pattern of *Petromyzon marinus* near its spawning beds.

From my own observations at Pemberton, Western Australia, I can add that the great majority of individuals which, according to body form, would be classified as *'Yarra'*, have dull, blue to brownish-grey coloration, darker above than below. In occasional individuals, green dorso-lateral stripes are just discernible below the almost opaque epidermis. It is obvious that colour pattern is not a good character for distinguishing lampreys near their upstream spawning beds, and the lack of bright coloration in pouched specimens is consistent with their having been longer in the rivers than the unpouched forms.

Conclusion

It may be argued that these considerations do not *prove* that *'Yarra'* is the 'velasia' stage of *Geotria*. Whitley (1940) has intimated that it may be a neotenous form, which is to say that it is a species which becomes sexually mature while possessing the other characteristics of an immature stage of a related species—presumably *Geotria australis*. This hypothesis assumes, therefore, the existence of a 'velasia' stage in the life-history of *Geotria* but fails to offer any criteria, apart from sexual maturity, whereby *'Yarra'* may be distinguished from it. The argument therefore turns on the sexual maturity of *'Yarra'*, for which no evidence has been put forward in opposition to the findings of Dendy and Olliver (1901). It should be borne

in mind, in view of Maskell's (1929) finding that only male *Geotria* have large pouches, that *'Yarra'* would need more substantiation than the discovery of a pouchless mature female.

The occurrence of neotenous, 'non-parasitic' lampreys in the Northern Hemisphere is so widespread that it would not be surprising to find some such instance among the southern forms but, as yet, there is no evidence of them. There is therefore no reason to depart from the finding of Dendy and Olliver (1901) that *Velasia stenostomus* Ogilby 1896 is synonymous with *Geotria australis* Gray 1851. The ammocoete which was described as *Yarra singularis* Castelnau, (1872) is now missing and the description is insufficient to allow its separation from ammocoetes of *Geotria australis* Gray (1851). I am of the opinion that *Yarra singularis* Castelnau must be treated as a synonym of *Geotria australis* Gray.

Acknowledgments

I wish to express my gratitude to Dr. E. Trewavas of the British Museum (Natural History) and to Dr. W. D. L. Ride of the Western Australian Museum for granting access to their collections of lampreys, and to Mr. P. H. Greenwood for his helpful criticism of the manuscript of this paper.

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7.—Late Quaternary Eustatic Changes in the Swan River District

By D. M. Churchill*

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Pollen analyses have been made on a submerged fresh water peat from 68 feet below sea level. The radiocarbon age of this peat is 9,850 ± 130 years before 1958. The implications of change in sea level are discussed. Late Quaternary shore lines to the west of Fremantle have been mapped and show that Rottnest and Garden Islands have been isolated from the mainland since about 5,000 B.C.

Introduction

In 1957, through the courtesy of Mr. G. F. U. Baker, the Main Roads Department kindly offered the author a number of samples from bores drilled for the construction of a bridge over the Swan River at "The Narrows," between Mount Eliza and Mill Point near Perth.

One of these samples was an old submerged peat from Bore No. 7, at a depth of 68 feet below mean sea level. A pollen analysis was made of this sample in the University Department of Botany, and the peat was then dried and sent to the New Zealand Department of Scientific and Industrial Research, Division of Nuclear Sciences, for radiocarbon dating. The age given for this sample (No. CR.721) was 9,850 ± 130 years before 1958 (B.P.)

Pollen Analysis

The sample of peat was black, hard and brittle when dry, breaking with a conchoidal fracture. It dissolved readily in boiling alkali (10% KOH) and the residue was then treated with acetic anhydride and concentrated sulphuric acid in the proportions 9 : 1.

The following pollen types were identified in preparations from the residues:

Eucalyptus wandoo
E. gomphocephala
Casuarina
Acacia
Myriophyllum
Pteridium
Cyperaceadites
Proteacidites
Hystrichosphaerideae
Fungal hyphae

Preservation of the grains was very good, the only indication of alteration being the loss of the exospore from *Pteridium* spores. This also occurs in preparations of spores from living material and is serious, as it prevents the distinction being made between fossil spores of *Pteridium* and those of *Cyathea*. As the present Australian species of *Cyathea* are confined to the Eastern States, it is probable although by no means proved, that the spores in this peat are those of *Pteridium* (Bracken fern).

Eucalyptus pollen was the most abundant and showed a similarity both in size and morphology to living Wandoo (*Eucalyptus wandoo* Blakely), and Tuart (*E. gomphocephala A.D.C.*). The Hystrichosphaerideae are represented by two forms, both of which are found in brackish to fresh water swamps along the coast between Walpole and Flinders Bay. The presence of the swamp plant *Myriophyllum* confirms the brackish to fresh water conditions of the peat, and the preservation of fungal hyphae suggests deposition under aerobic conditions. The present distribution of the Tuart shows edaphic restriction to the Coastal Limestone, but Wandoo, where it occurs on the Swan Coastal Plain, is confined to clay. Both species are still found along the Swan River but nowhere do their present distributions overlap.

It is now thought that 9,850 ± 130 years B.P. or at approximately 7,900 years B.C., when the Swan River was more than 68 feet below its present level, swampy clay flats were exposed along the river banks in the vicinity of Mill Point and Mount Eliza. The clay soils of this area supported Wandoo, while nearby calcareous soils supported Tuart.

Significance of Sea Level Changes

The low stand of water level at the Narrows 9,850 years ago supports the observations of Baker (1956), that Melville Water and Freshwater Bay cover an ancient drowned river channel at 60-75 feet and 120-140 feet below datum.

More important however, is the fact that when sea level was 68 feet or more below its present level, Rottnest, Carnac and Garden Islands would have been high ridges on a coastal plain extending out from the mainland, to what is now the 11 fathom line.

Godwin, Suggate and Willis (1958) have collected data on radiocarbon dated samples, thought to represent local low stands of sea level, from such widespread localities as the Gulf of Mexico, New Zealand, Victoria, the South Baltic, British coast and the Persian Gulf. By collating this data, local isostatic effects have been masked by the general trends, thereby enabling a more accurate record of the history of eustatic rise in sea level to be made. The data of these workers have been plotted in Fig. I, together with the dating from the Narrows Bore, No. 7. This date agrees so well

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with the trends of Godwin and his co-workers that it seems safe to assume that in the Swan River District, over the past 14,000 years, eustatic changes have been more active than isostatic change.

It is apparent that sea level has steadily risen from forty fathoms in 12,000 B.C. to the same level as now, in 3,000 B.C. How high the sea rose before returning to its present level is still unknown. However, fossil coral reefs from Dirk Hartog Island (B. Logan, pers. comm.), Abrolhos Island (Teichert 1947), and Rottnest Island (Teichert 1950) are found with their upper surfaces standing at 5, 11 and 6 feet respectively above mean sea level. If these coral reefs are younger than 3,000 B.C., sea level over the last 5,000 years has been at least 10 feet higher than now and has subsequently lowered to its present level.

If the present bathymetry of the continental shelf to the west of Fremantle can be taken as an indication of old shorelines as sea level rose throughout the Recent, then the position of these strandlines may be mapped. Fig. 2, A, B, C, and D have been prepared from data on Admiralty Chart No. 1058 published in 1955, with small corrections to 1957.

From Fig. 2 the following events can be summarized:—

1. Rising sea level since 12,000 B.C. has flooded and drowned an old dune topography situated between Perth and Rottnest.
2. Cockburn Sound was an interdunal lake before rising seas flooded it. This flooding is thought to have taken place between 3,000 and 4,000 B.C.
3. The Swan River crossed the exposed coastal plain in 6,000 B.C. and discharged into a wide bay about 5 miles E.N.E. of Rottnest.
4. If the present five fathom contour line is taken as forming the last continuous land bridge from Rottnest to Garden Island and the mainland, then Rottnest has been cut off from this peninsula, as an island, since approximately 5,000 B.C. Garden Island was probably cut off from the mainland at the same time, although numerous small islands would have existed between Cape Peron and the southern end of Garden Island.

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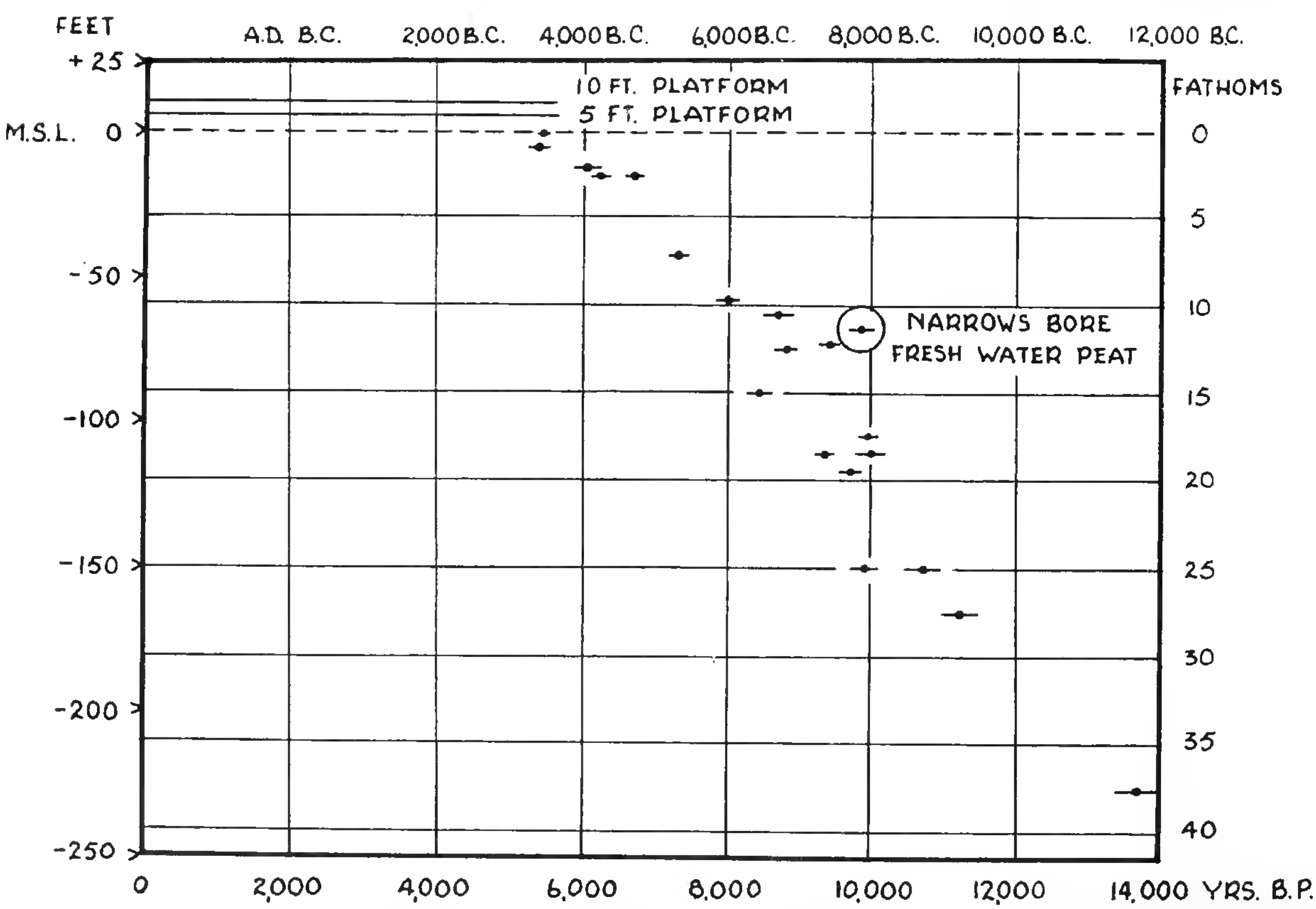

Fig. 1.—Eustatic changes of the sea to the present level, as indicated by samples deposited close to their contemporary levels. Data mainly from Godwin *et al.* but including samples from "The Narrows."

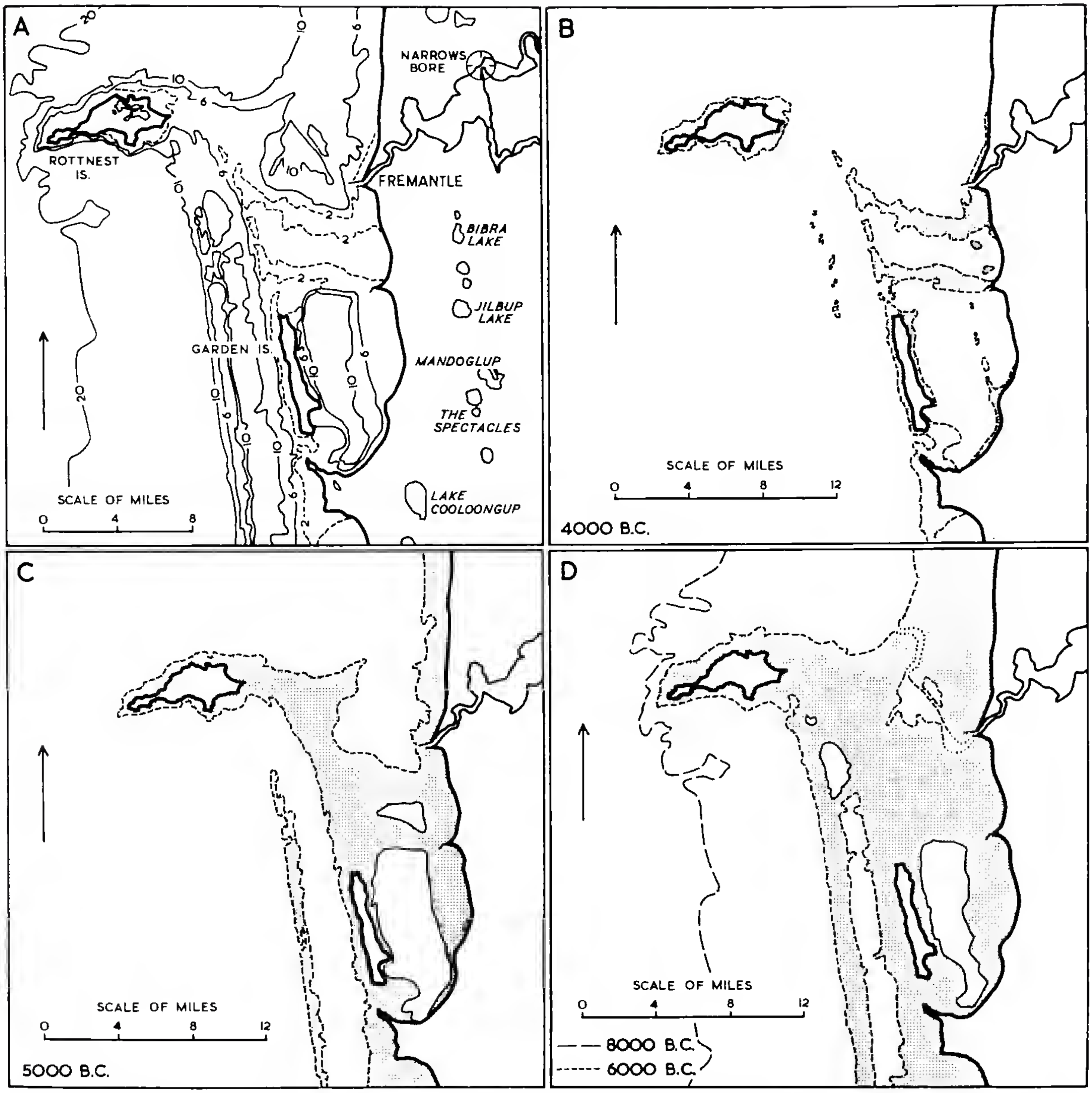

Fig 2.—(A) Present bathymetry Fremantle-Rottnest Island area. (B, C, D) Location of shorelines at 4,000, 5,000, 6,000 and 8,000 B.C., as deduced from rate of sea level change and present bathymetry. Stippled area shows extent of exposed coastal plain, beyond its present configuration.

8.—Notes on the Fabric of Some Charnockitic Rocks from Central Australia

By Allan F. Wilson*

Manuscript received—17th March, 1959

An exploratory study shows that in some charnockitic granulites the quartz fabric gives reasonable confirmation of the field evidence that the observed lineation is in the axial direction of folds. In others the quartz fabric has triclinic symmetry, suggesting some over-printing of the quartz fabric by later earth movements. In such rocks, however, other minerals such as hornblende, scapolite and possibly hypersthene are more reliable indicators of the direction of fold axes. In a major flat-lying plastic shear zone on which transcurrent movement is postulated, a prominent quartz girdle is developed about the strong lineation which plunges down the dip of the shear zone. The lineation is thought to be in *b* not *a*.

Introduction

While investigating the extensive area of charnockitic rocks in Central Australia, petrofabric studies were made of some of the rocks. This was done to try to confirm the field evidence that most of the observed lineations are approximately parallel to fold axes. This is a problem, because, in this little-known area, there is conflicting evidence of the relation between the prominent E.-W. trending ranges and the widespread N.-S. trend of the fold axes and lineation (shown by mineral elongation) in large areas within these ranges.

The charnockitic rocks from Central Australia have been described in several papers (for latest-review, see Wilson 1959). The following is a brief summary of the main features. The oldest rocks are charnockitic granulites, many of which are of sedimentary origin. Although some of the acid rocks are khondalitic, the bulk of the gneisses are adamellitic or granodioritic in composition, and probably represent both original greywackes and primitive igneous rocks, all of which have been subject to deep-seated regional metamorphism.

Interfoliated with these rocks are contorted bands and boudins of basic charnockites. Some of these probably represent original basic intrusions. but for others a sedimentary origin is probable. Owing to the plastic deformation which the host rocks have undergone in most areas, some of the basic bands were probably discordant dykes which have been drawn into conformity during metamorphism. Some of the basic charnockites have been converted into intermediate and acid charnockitic rocks by granitization and other metasomatic changes.

From Fig. 1 it will be seen that the foliation of the basement rocks is roughly meridional for at about 150 miles across the strike, i.e., throughout the central and eastern Musgrave Ranges. In many places the gneisses have been thrown into folds, many of which are tight, and all of which are ornamented with minor folds. Although the trend of the fold axes, and of a lineation are approximately meridional, there is the complication of gentle cross-folding or warping on E.-W. lines.

In the Ayers Ranges (particularly in the eastern half) the gneisses are folded on approximately meridional axes, and the lineation is essentially parallel to fold axes where these are known. In the Kulgera Hills the tectonic trend (as shown by tight fold axes and lineation and average strike-trends) is between 330° and 340°.

The basement rocks of the Musgrave Ranges are mostly of granulite facies, but many of those of the eastern portion of the Ayers Ranges, and all of those of the Kulgera Hills, are typical of high levels of the amphibolite facies.

In the Musgrave Ranges the whole complex of charnockitic granulites (and later gabbroic intrusions and anorthosites) is cut by large masses of charnockitic ferrohypersthene adamellite and granodiorite which have moved (probably as rheomorphic crystal mushes) into their present position.

In the Ayers Ranges and Kulgera Hills, hornblende granites and sphene-bearing granites, closely related to the charnockitic intrusions of the Musgrave Ranges, have been emplaced into basement rocks which in those areas are largely of upper amphibolite facies.

Extensive field work must precede the explanation of the apparent contradiction of the long E.-W. string of petrologically closely-related magmatic granites, many of which form N.-S. bodies sub-parallel to the linear structures and major fold structures of the basement rocks. It it tentatively suggested, however, that a regional deep-seated E.-W. downwarp (possibly associated with deep-seated E.-W. transcurrent shearing) may have been sufficient to have caused thorough reconstitution of the basement rocks, and to have produced "pockets" of potential magma in favourable areas. Subsequent emplacement of the resultant rheomorphic masses would be assisted by pre-existing weaknesses due to the N.-S. attitude of many of the original rocks.

Notwithstanding the obvious structural complications, it was decided to make a preliminary study of some quartz fabrics in the first instance. This was done, moreover, despite the

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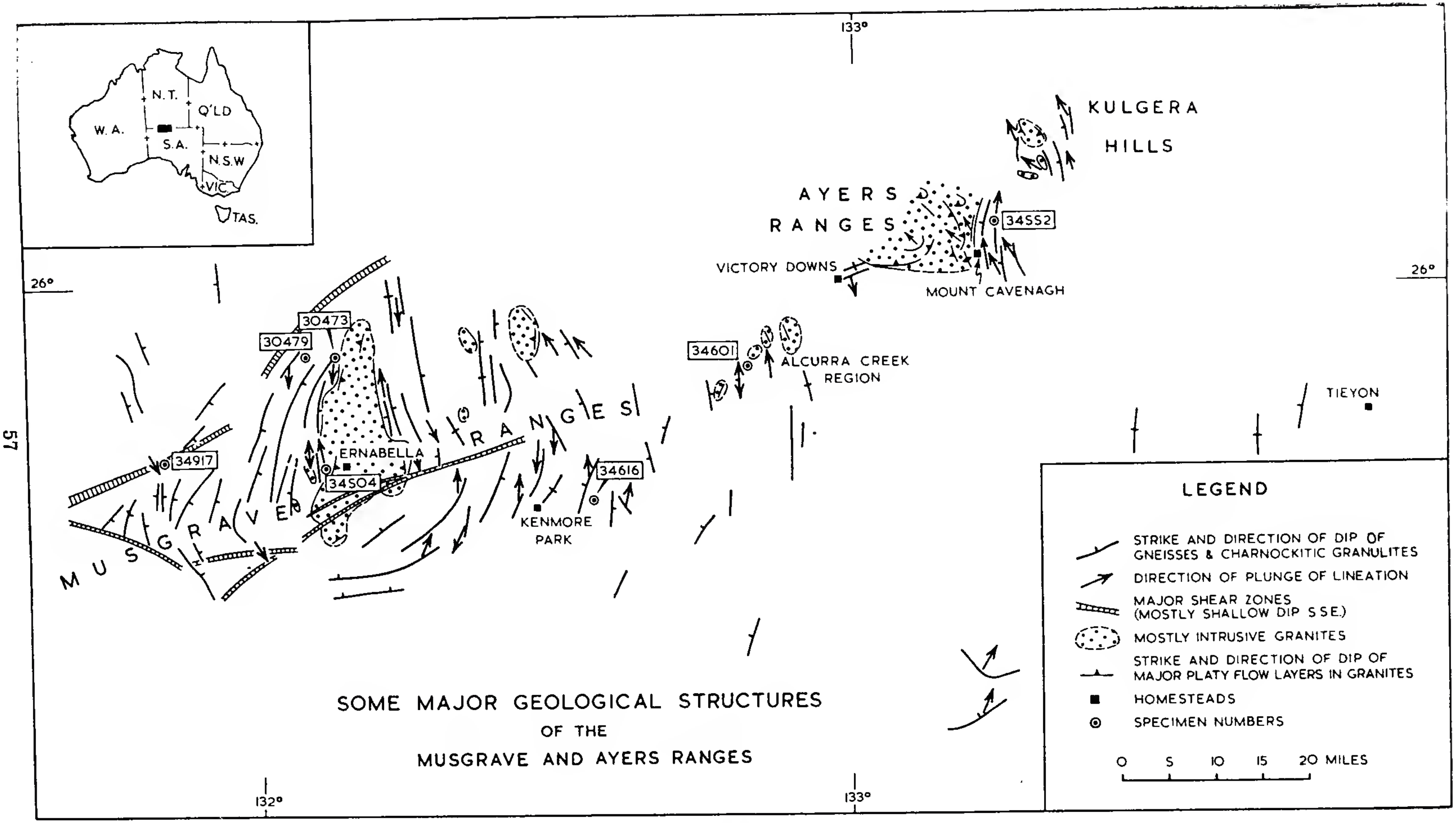

SOME MAJOR GEOLOGICAL STRUCTURES
OF THE
MUSGRAVE AND AYERS RANGES
W. A.
N. T.
Q'LD
S.A.
N.S.W
VIC
TAS.
26°
133°
132°
MUSGRAVE RANGES
AYERS RANGES
KULGERA HILLS
VICTORY DOWNS
MOUNT CAVENAGH
ALCURRA CREEK REGION
ERNABELLA
KENMORE PARK
TIEYON
30473
30479
34917
34504
34616
34601
34552
LEGEND
STRIKE AND DIRECTION OF DIP OF GNEISSES & CHARNOCKITIC GRANULITES
DIRECTION OF PLUNGE OF LINEATION
MAJOR SHEAR ZONES (MOSTLY SHALLOW DIP S.S.E.)
MOSTLY INTRUSIVE GRANITES
STRIKE AND DIRECTION OF DIP OF MAJOR PLATY FLOW LAYERS IN GRANITES
HOMESTEADS
SPECIMEN NUMBERS
0 5 10 15 20 MILES

Fig. 1

fact that Sahama had found difficulty in interpreting many unusual quartz fabrics from the granulites of Lapland (Sahama 1936). Difficulties were soon encountered, for quartzites are absent, mica is rare, and there are no marbles to assist in correlation of fabric results. Hence, measurements had to be made on rocks of various types, some of which contain only a small percentage of quartz. Moreover, only a few suitably oriented specimens are available. The reason for this is that several important areas were mapped as early as 1943 when I did not fully appreciate the need for oriented specimens. Thus, the present study is merely exploratory. Certain results, however, are useful, and may guide future workers in this field.

Fabric Analysis

The following are some notes on the fabric of several rocks.

Specimen No. 34504†.—This rock, a medium-grained poorly banded hypersthene-microperthite-andesine-quartz granulite, is typical of the acid charnockitic granulites of the Musgrave Ranges (Fig. 1). It crops out one-quarter mile ESE. of Harris Springs near Ernabella. The strike is 175°, dip 85° W.; the lineation plunges 20° due S. and is parallel to the axes of minor and major folds, most of which are nearly isoclinal in this area.

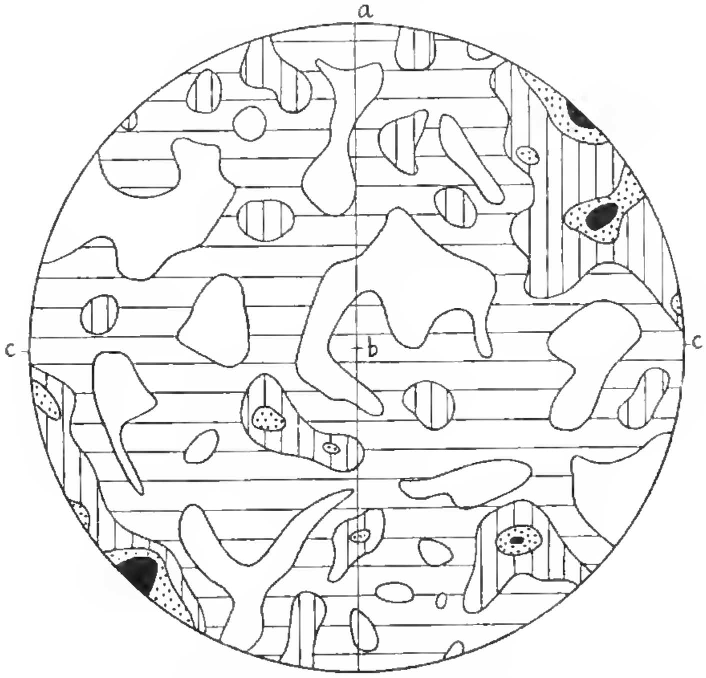

Fig. 2.—*Acid charnockitic granulite* (34504) near Ernabella, Musgrave Ranges. Orientation diagram of 300 *quartz* optic axes in section normal to lineation which plunges 20° due S. Banding in granulite (shown by line *ab*) has strike 175° and dip 85° W.

Orientation: Looking N. along lineation *(b)* with top of diagram the approximate top of specimen.

Contours: 0, 2, 3, 4, (including 5% maximum).

Fig. 2 shows the orientation of 300 quartz optic axes in a section cut normal to the lineation. There is a weak *ac*‡ girdle with a maximum about midway between *a* and *c* in quadrants one and three. The presence of a submaximum within quadrant three suggests that an incomplete girdle may also pass through *b* thus linking the main maxima in quadrants one and three. However, the concentrations away from the edge of the diagram may be due to overprinting of an original fabric. If significance is to be placed on these, the symmetry of the fabric would fall from monoclinic to triclinic.

Hornblende is absent and biotite very rare, but hypersthene has a tendency to be flattened in the *ab* plane. In an interbedded rock a few biotite flakes are found, and these have cleavage planes parallel to *ab*. In other associated rocks hornblende is well alined with its *c* crystallographic axis parallel to the lineation, and its *b* crystallographic axis more or less parallel to *a*. Notwithstanding some possible overprinting of the quartz fabric, the total fabric of this rock would seem to confirm the field evidence that the lineation is parallel to the fold axis.

Specimen No. 30473.—This rock is a medium-grained banded hypersthene-microperthite-quartz-andesine granulite, and is typical of the extreme NE. tip of the range to the N. of Alalka, and crops out about three miles E. of Wardulka rock-hole. The strike is 50°, dip 30° SE. and there is a fair lineation plunging 10°-15° in a direction 185°. Reference to the map (Fig. 1) shows that the rock occurs near the nose of a major syncline (plunging flatly S.), and its lineation is in the axial direction of that fold. 34504 (described above) is taken from a position on the W. flank of the same structure.

The specimen was collected during my 1943-1944 expedition to the area and is not orientated. However, a section was cut approxi-

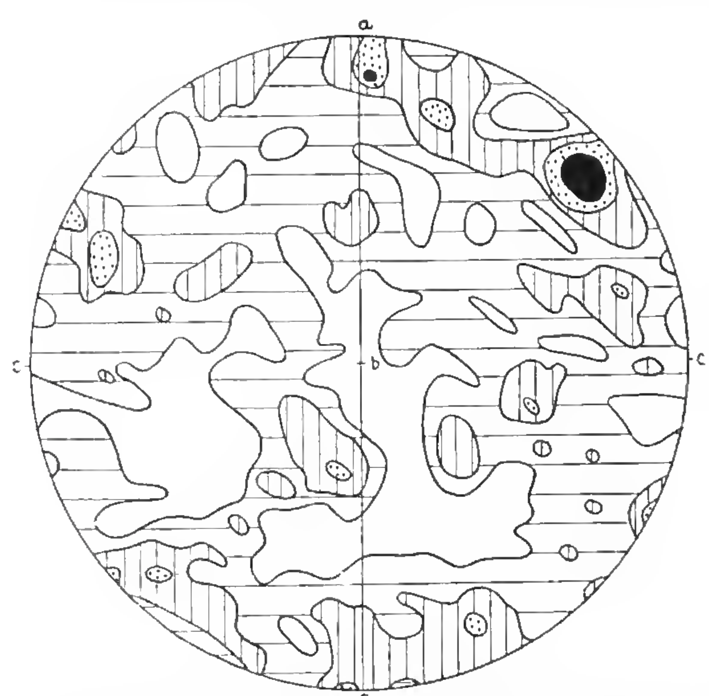

Fig. 3.—*Acid charnockitic granulite* (30473) ESE. of Wardulka, Musgrave Ranges. Orientation diagram of 300 *quartz* optic axes in section normal to lineation *(b)* which plunges 10° to 15° in direction 185°. Banding in granulite (shown by line *ab*) has strike 50° and dip 30° SE. Non-oriented specimen.

Contours: 0, 2, 3, 4 (including 5% maximum).

† All numbers refer to specimens in the rock collection of the University of Western Australia.

‡ Sander's original terminology is used in this paper (as in Cloos 1946, p. 6): *b* is fold axis, *a* is perpendicular to *b* in the movement plane, and *c* is perpendicular to *ab*.

mately normal to the lineation as seen in the hand-specimen, and the orientation of 300 optic axes of quartz was measured (see Fig. 3). As in 34504, there is a weak *ac* girdle with a maximum between *a* and *c*. Minor concentrations recall those seen in 34504.

A preferred orientation of plagioclase (with 001 $\perp$ lineation) was suspected, but not measured. Biotite is absent, and the small amount of hypersthene (3%) shows no obvious preferred orientation. Strictly speaking, the fabric has triclinic symmetry, possibly due to overprinting of the quartz fabric, but it is close to monoclinic symmetry, and thus tends to confirm that the lineation is parallel to the fold axis.

Specimen No. 30479.—This rock, a medium-grained banded hypersthene-hornblende-microperthite-quartz-andesine granulite of granodioritic composition, is well exposed at the Wardulka rock-hole. It is a partly granitized relic of a basic band set in an otherwise fairly homogeneous adamellitic pyroxene granulite (like 30473). The strike is 20°-30°, dip 40° S. and there is a fairly good lineation plunging about 5° in a direction 185°. Reference to the map (Fig. 1) shows that the lineation is in the axial direction of the same major S.-plunging syncline to which both 34504 and 30473 are referable. Axes of nearby tight drag folds (two to three feet from crest to trough) plunge at low angles almost due S. The specimen was collected during the 1948-1949 expedition and unfortunately is not orientated. However, a section was cut normal to the well lineated hornblende crystals, and 300 optic axes of quartz were measured (see Fig. 4).

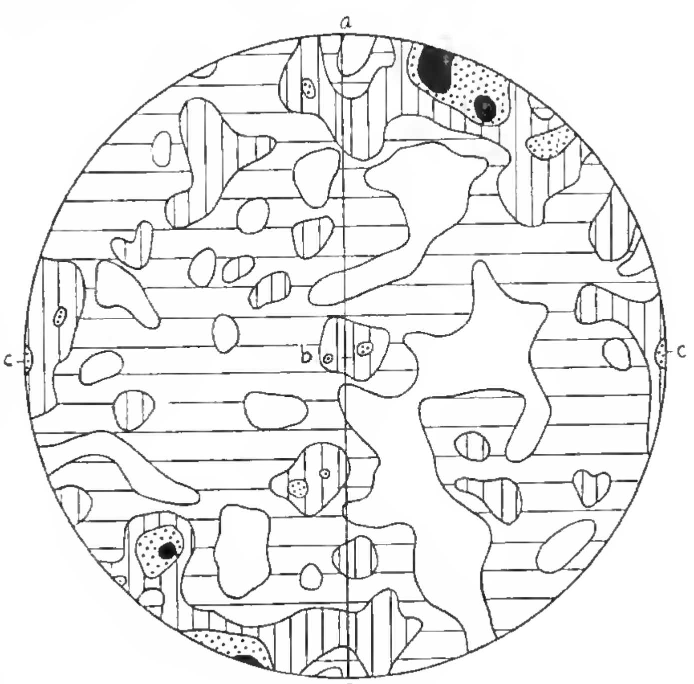

Fig. 4.—*Acid charnockitic granulite* (30479), Wardulka, Musgrave Ranges. Orientation diagram of 300 *quartz* optic axes in section normal to lineation *(b)* which plunges about 5° in direction 185°. Banding in the granulite (shown by line *ab*) has strike 20° to 30° and dip 40° S. Non-oriented specimen.
Contours 0, 2, 3, $3\frac{1}{2}$ (including 4% maximum).

In this rock, although the quartz shows a poor girdle about *b*, the symmetry of the diagram is triclinic. The minor concentrations near the centre and within quadrant three (as here orientated) even suggest a partial girdle through *b* and oblique to *ab*. There is also a submaximum appearing at *c*. The hornblende is well orientated with the crystallographic *c* axis parallel to the *b* lineation, and the crystallographic *b* axis parallel to the *a* fabric axis. Mimetic growth of reaction-quartz as granules intimately associated with the hornblende crystals could account for the small but significant concentration of quartz optic axes at *b*.

Specimen No. 34552.—This rock, which is typical of the gneisses of the Ayers Ranges, is a biotite-bearing granitic gneiss in which a few granules of hypersthene remain to indicate its affinity with the charnockitic granulites of the Musgrave Ranges to the W. It occurs ($3\frac{3}{4}$ miles NNE. of Mt. Cavenagh Homestead) on the E. limb of a syncline in a series of folds which plunge 45° in a direction 10° (see Fig. 1). The well-developed lineation is clearly parallel to the axes of the folds.

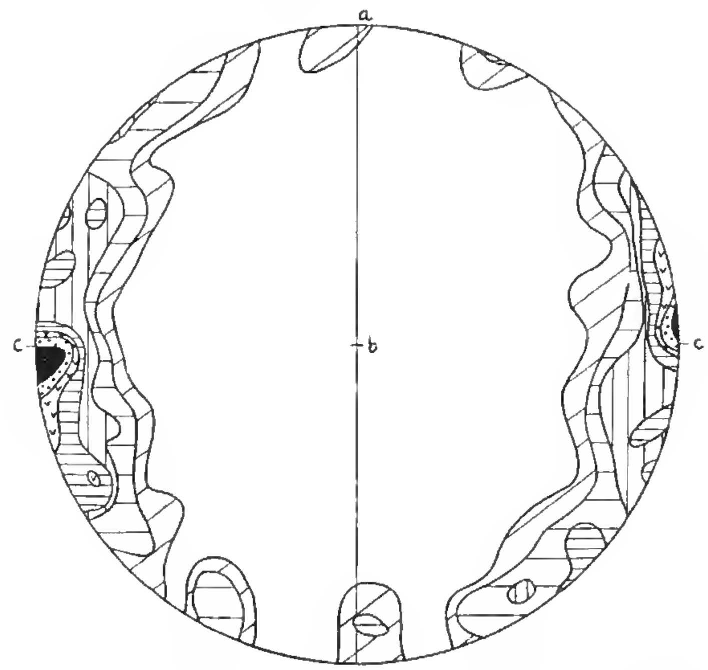

Fig. 5.—*Biotite-bearing acid charnockitic gneiss* (34552) near Mt. Cavenagh Homestead, Ayers Ranges, Central Australia. Orientation diagram of 100 cleavage poles of *biotite*. Orientation as for Fig. 6.
Contours: 0, 2, 4, 6, 8, 10, 12 (including 14% maximum).

A microfabric study of 100 cleavage poles of biotite (Fig. 5) confirms the foliation (= bedding) is the *ab* plane which strikes 40° and dips 50° N.W. A plot of 300 quartz optic axes, however, demonstrates clearly that there has been some overprinting of the quartz fabric (Fig. 6). The maxima do not fall in the *ac* plane, nor on any single great circle. Without a study of other rocks from the area it is impossible to say which maxima (if any) are original and which are due to superimposed forces.

Large granite intrusions have been emplaced nearby. Linear flow-lines and general attitude of well-developed platy flow-layers indicate that important stresses must have acted on the area from a direction probably 45° away from those which controlled the formation of the original folding and lineation in the fold axis

direction. The stresses associated with the emplacement of the granite presumably were able to modify the quartz fabric without appreciably affecting the orientation of biotite or the macroscopic lineation in *b*. This confirms the long-recognized fickle behaviour of quartz in metamorphic rocks, and demonstrates the need for caution in the use of quartz diagrams where superimposed earth movements are suspected. A corollary of considerable practical importance, however, is that a macroscopic lineation (originally in the fold axis direction) may be expected to survive superimposed stresses of moderate rigor, and, with caution, may be used to decipher the folding of the lineated rocks.

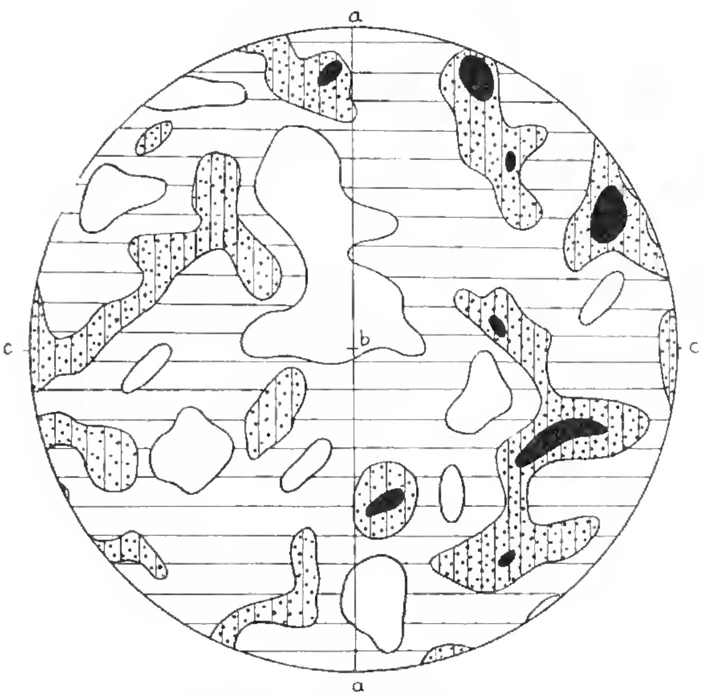

Fig. 6.—*Biotite-bearing acid charnockitic gneiss* (34552) near Mt. Cavenagh Homestead, Ayers Ranges, Central Australia. Orientation diagram of 300 *quartz* optic axes in section normal to lineation which plunges 45° in a direction 5°. Foliation (shown by line *ab*) has strike 40° and dip 50° NW. Orientation: Looking approximately N. along lineation (*b*) with horizontal line on specimen approximately tangent to the 2nd quadrant.
Contours: 0, 2, 3 (including 3½% maximum).

Specimen No. 34601.—This rock is a cordierite-sillimanite-bearing granitic gneiss which lies between the Ayers Ranges (e.g. 34552) and the Musgrave Ranges. It crops out 14 miles WSW. of Victory Downs Homestead, and two miles WSW. of the Alcurra Creek Crossing on the track to the Musgrave Ranges. The strike is 354°, dip 70°-80° E., and a good lineation (shown by small sillimanite needles) plunges 2°-3° toward 354°. This lineation, which is parallel to the axes of several small folds, is meridional in trend and comparable with that observed in most parts of the Ayers Ranges to the E., and in the Musgrave Ranges to the W.

Figure 7 shows the orientation of 300 quartz optic axes. Although there is a weak girdle about *b* there is no symmetry about the *ab* plane. If *a* be moved about 20° into quadrant one to a^1, the quartz maxima display approximate symmetry about the a^1b plane. Unfortunately, there is insufficient biotite in this rock to

Fig. 7.—*Acid cordierite-sillimanite gneiss* (34601), Alcurra Creek region between Musgrave and Ayers Ranges, Central Australia. Orientation diagram of 300 *quartz* optic axes in section normal to lineation (*b*) which plunges 2° to 3° in direction 354°. Foliation (shown by line *ab*) has strike 354° and dip 70° to 80° E. Orientation: Looking N. along lineation with top of diagram the approximate top of specimen.
Contours: 0, 2, 3 (including 4% maximum).

see whether the *ab* plane could be fixed more accurately than by the foliation trace. Since lineation is made macroscopically visible mainly by the elongation of sillimanite needles, and since it can be shown that the quartz crystallized much later than the sillimanite, it is possible that the quartz maxima were developed during a late stage of the same orogeny when the stress directions were somewhat modified.

Since this rock lies close to a large intrusive granite, stresses sufficient to partly overprint the quartz fabric but not to re-orientate the sillimanite needles are almost certain to have been in action. It will be recalled that similar interference was postulated for 34552 from the Ayers Ranges.

Notwithstanding the possible effect of the granite, the field evidence is clear that the lineation as shown by the sillimanite needles is still parallel to an original fold axis. Obviously, however, more than one orientated rock is needed to elucidate the quartz fabric of the gneisses of the area.

Specimen No. 34616.—This rock is a scapolite-bearing basic charnockite collected from good outcrops 200 yards E. of No. 7 Well, about seven miles E. of Kenmore Park Cattle Station in the eastern Musgrave Ranges. Basic and intermediate granulites are common in the vicinity, and, as with the interbedded enderbites, they have a good lineation with a flat plunge due N. The rocks have been folded on meridionally-trending axes, and the lineation is consistently parallel to the fold axes. The strike of 34616 is 19°, dip 35° W., and lineation plunges 3°-5° in a direction 2°.

1

2

PLATE I

1.—Lineation (parallel to small hammer handle) on mylonitized rocks in the Woodroffe Shear zone as exposed in Brown's Pass, Musgrave Ranges (see locality of specimen 34917). Strike 238° (parallel to large hammer handle), dip 8° to 10° SE. with strong lineation plunging 8° to 10° in direction 140°. Looking approximately W.

2.—Shredded masses of quartz (white) more or less in optical continuity over considerable areas. A few rounded relics of feldspar (dark grey) are present. Note the s-shaped swirls (especially, quadrant 4) which suggest that in this sheared rock the direction of movement was normal (not parallel) to the direction of lineation. Section normal to lineation in *mylonitized granitic gneiss* (34917). Brown's Pass, Musgrave Ranges. Crossed nicols, x25.

An attempt was made to measure the orientation of quartz in certain contorted leucocratic schlieren in the basic rock. Only 200 grains could be measured, and the fabric diagram appears as Fig. 8. No symmetry is revealed in this diagram, and the only important maximum seems to lie off the periphery and some 20° from *a*.

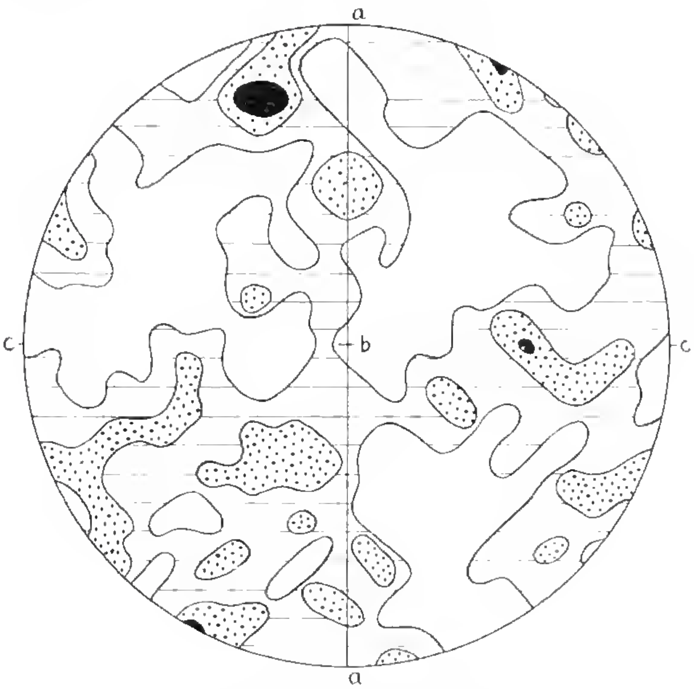

Fig. 8.—*Scapolite-bearing basic charnockite* (34616) from 7 miles E. of Kenmore Park Homestead, Musgrave Ranges. Orientation diagram of 200 *quartz* optic axes in section normal to lineation *(b)* which plunges 3° to 5° in a direction 2°. Banding (shown by line *ab*) has strike 19° and dip 35° W.

Orientation: Looking N. along lineation with horizontal line of specimen approximately tangent to 2nd quadrant.

Contours: 0, 2, 3 (including 4% maximum).

The hornblende of this rock is well alined with its *c* axis parallel to the lineation and fold axes of the area. There is no obvious preferred orientation of the *b* crystallographic axis in the *ab* fabric plane such as was found in 30479.

Scapolite, a rare mineral in the charnockitic granulites of the Musgrave Ranges, comprises about 12 per cent of the basic portions of the rock. Petrographic evidence is that it formed at the same time as the pyroxenes and hornblende, and is thus not a secondary mineral. The orientation of the optic axes of 100 grains of scapolite was measured, and an incomplete girdle about *b* was found (Fig. 9). There is no symmetry about the *ab* plane and the maxima are all several degrees within the periphery. Little is known of the orientation of scapolite in deformed rocks—the only reference noted would indicate that the *c*-axis becomes oriented in the *ab* plane (Fairbairn 1949, p. 9).

It would appear, therefore, that in this rock quartz has failed to give confirmation of the field evidence that the lineation is in *b*. The hornblende and possibly scapolite are more reliable.

Specimen No. 34917.—A prominent zone of intense shearing extends for at least 40 miles ENE. from the N. face of Mt. Woodroffe.

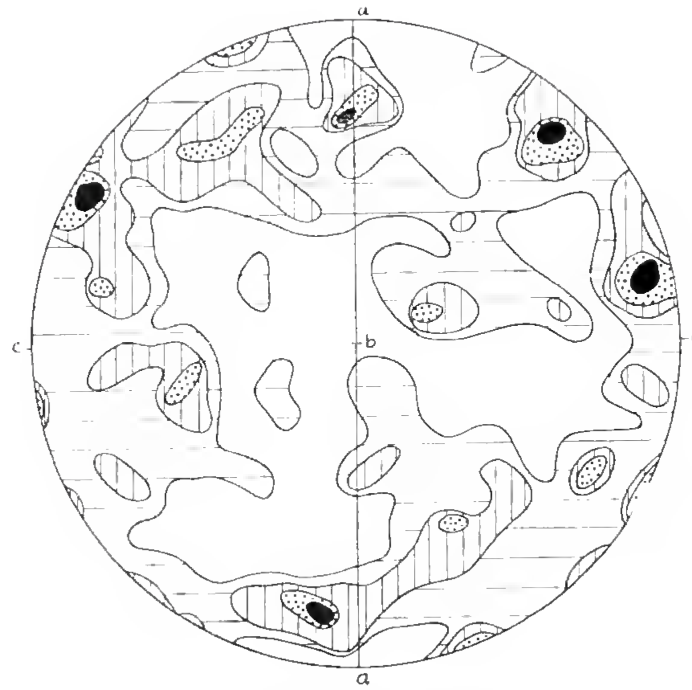

Fig. 9.—*Scapolite-bearing basic charnockite* (34616) from 7 miles E. of Kenmore Park Homestead, Musgrave Ranges. Orientation diagram of 100 *scapolite* optic axes in section normal to lineation *(b)*. Orientation as in Fig. 8.

Contours: 0, 2, 3, 4 (including 5% maximum).

Gneisses and granulites of various kinds occur within this shallow-dipping zone which is upwards of one half-mile wide in outcrop. In places the rocks are intensely mylonitized, and dense chert-like rocks and pseudo-tachylytes are common. The plastic shearing did not necessarily take place at great depth, but the presence of tiny garnets (less than 0.05 mm.) indicates the development of considerable local heat. Thin-sections of any of the rocks from the zone are readily recognized by the extreme shadowy extinction and shredded nature of the quartz and feldspars and the common development of "shredded" biotite and tiny garnets instead of pyroxene and calcic plagioclase.

Figure 10 shows the orientation of 150 optic axes of quartz from a heavily sheared and well lineated granitic gneiss (34917). The rock occurs on the E. side of the N. mouth of Brown's Pass. Here the rocks have suffered considerable shearing and the resultant rock looks flaggy in the field (Plate 1, 1). The strike is about 238°, and dip is 8° to 10° SE., and there is a strong lineation plunging 8° to 10° in direction 140°. Figure 10 is statistically weak because large quartz grains have been shredded into 20 or more irregular pieces, many of which cannot be measured (Plate 1, 2). At least 1,000 grains would need to be measured before the position of quartz maxima could have much significance. Notwithstanding the poor statistical value of the diagram, it is clear that not only is there a marked girdle about the lineation, but it shows monoclinic or even orthorhombic symmetry. This girdle is much more pronounced than anything seen in the normal granulites of the area.

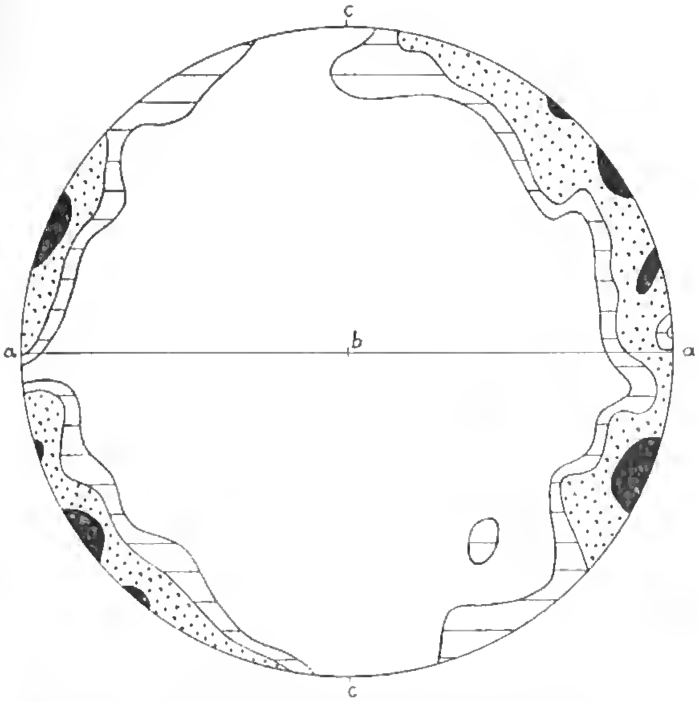

Fig. 10.—*Mylonitized granitic gneiss* (34917), Brown's Pass, Musgrave Ranges. Orientation diagram of 150 *quartz* optic axes in section normal to strong lineation *(b)* which plunges 8° to 10° in direction 140° (i.e., down-dip). Banding (shown by line *ab*) has strike 238° and dip 8° to 10° SE. Orientation: Looking N.W. along the lineation with top of diagram the approximate top of specimen.
Contours: 0, 3, 6 (including 9% maximum).

Indeed, the fabric diagram and field occurrence are such that some would interpret the structure as a thrust, and the lineation as an *a*-lineation. Thus, Kvale states that in a thrust zone, "where the main lineation is parallel to the principal direction of movement the diagrams have a perfect monoclinic symmetry, the plane of symmetry being perpendicular to the lineation . . . " (Kvale 1953, p. 59). Joklik has made similar observations on rocks from thrust zones in the Harts Range (Townley and Noakes, 1954, p. 151). Indeed, several authors maintain that there is evidence that lineation in *a* is typical of areas affected by "thrust tectonics," and that the more common lineation in *b* is more characteristic of areas affected by "fold tectonics."

This flat-lying shear zone in Central Australia has been called a thrust (namely, the Woodroffe Thrust). Since a prominent lineation is almost directly down-dip, it has been assumed that the direction of movement on the thrust was in the direction of the lineation, that is, S. block up and N., with little strike-slip component. I once held this view myself, beguiled (as I fear others have been) by the assumption that flat-lying faults must be thrusts, and that lineation on rocks in a fault zone is always in the direction of movement on the fault. If one argues in circles in this way it is easy to "prove" that lineation on a fault is an *a*-lineation.

In the rock under discussion, s-shaped swirls are evident in thin-sections cut normal to the lineation (Plate 1, 2). Thus, the direction of movement is normal (not parallel) to the direction of lineation.

It is my belief that the effects of the deformation which has produced the mylonitized rock under discussion were not restricted to the mylonitized zone. Indeed, it is likely that this zone is merely a zone where the tectonic forces have become more concentrated, thus causing the gneisses to flow more readily in a "plastic" manner. As stresses are built up, open folds become isoclinal folds, and in some places more so than in others a rigid banding develops. Even though the limbs and eventually the thickened crests and troughs of folds become "smeared out," it would appear that if the process takes place at a high level of metamorphism (such as amphibolite or granulite facies) the lineation in these finely granulated, very regularly banded rocks will still represent the direction normal to the direction of dominant movement in the rock mass under deformation.

My present view is that the term "Woodroffe Thrust" should be replaced by "Woodroffe Shear-zone." The movement on this structure has been largely transcurrent (i.e., strike-slip). Indeed, deep-seated plastic shearing of this type may have taken place along a number of sub-parallel zones in the Musgrave Ranges. The strong couple developed between such zones may have been a major factor in producing in the gneisses and granulites many of the folds whose axes trend at a steep angle to the trend of the postulated transcurrent plastic shear zones.

The regional significance of the several great shear zones known in the Musgrave Ranges can scarcely be further discussed with profit while our knowledge of the fold patterns, and distribution of major igneous bodies and later basic dyke swarms of the area is so limited.

Conclusions

Preliminary work on several charnockitic granulites from Central Australia shows that in some rocks (e.g. 34504) the symmetry of quartz fabric is close to monoclinic, and thus gives reasonable confirmation of the field evidence that the observed lineation is parallel to fold axes (see Turner 1957). In others, however, the quartz fabric has triclinic symmetry, thus indicating some overprinting of the quartz fabric by later earth movements.

In rocks where the quartz has failed to give confirmation of the field evidence that the lineation is in the axial direction of the folds, other minerals such as hornblende, scapolite, sillimanite and possibly hypersthene have proved more reliable. Enough work has been done in this area to show that lineation (i.e., that developed from mineral elongation) in the normal gneisses and granulites is worthy of careful field record and use.

In a major flat-lying plastic shear zone (the Woodroffe Shear-zone) there is a strong lineation, and a fabric analysis shows that a very prominent quartz girdle of monoclinic (close to orthorhombic) symmetry has developed about the lineation which plunges in the dip direction. The lineation is thought to be in *b* not *a*, and the shear-zone is thought to represent a major transcurrent movement of considerable tectonic significance.

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